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Influence of density on selected properties of furniture particleboards made of raspberry *Rubus idaeus* L. lignocellulosic particles

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Abstract: *Influence of density on selected properties of furniture particleboards made of raspberry Rubus idaeus L. lignocellulosic particles*. The aim of the research was to determine the effect of density of three layer furniture particleboard, produced in laboratory conditions, in the three different densities: 500, 650 and 800 kg/m^3, on their selected mechanical and physical properties. The fraction share of the particles used, as well as bulk density of the produced particles have been also measured. The tests have shown that with increasing density of the tested panels in the mentioned range, there is a significant improvement of mechanical parameters, but the thickness swelling of the panels unfavorably raises. The density increase causes also changes in density profile.

Keywords: density; particleboard; alternative raw material; raspberry; density profile

INTRODUCTION

Optimal ratio of mechanical and physical parameters to the price of the particleboards lead to this, that the particleboards are still commonly used, especially in case of office and kitchen furniture, despite improvement of availability on the marked the new materials to furniture production. Due to this, the market demand for these panels is increasing. Since the wood raw material sources are limited, and wood has wide range of application in various branches, the necessity of seeking for new or alternative sources in needed.

There are wide range of research, conducted by industrial and academia side, towards finding an alternative lignocellulosic raw materials for particleboards and other wood-based composites production, which can fulfil the following requirements: annual renewability and/or fast growing, wide range of availability, easy processing (or at least similar to solid wood), relatively low price. The most promising results in this light have been achieved in case of following raw materials: 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. One of the limitation of application of these materials in industrial scale can be low density.

The goal of the research was to determine the influence of the density of three layer particleboards, produced from lignocellulosic particles of raspberry *Rubus idaeus* L., on the selected mechanical and physical properties of the panels. In the range of research, the modulus of elasticity when bending and bending strength have been measured, as well as internal bond, screw withdrawal resistance, water absorption, thickness swelling, density profile, particles mass fraction share and bulk density have been investigated.

MATERIALS AND METHODS

Raw material and investigated panels preparation

The investigated panels have been produced from the following lignocellulosic raw material: the annual stalks of raspberry *Rubus idaeus* L. with the average length of 0.7 m, diameter of 9.3 mm and moisture content (MC) of 8.6%; no debarking applied, used for face and core layers of particleboards.

The raspberry stalks were mechanically shredded 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. All the particles, have been dried to the MC about 5% and then were sorted to the fractions for core (8/2 mm mesh) and face (2/0.25 mm mesh) layer. 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.

A 16 mm – thick three layer particleboards, with face layers weight share of 32%, 100% raspberry particles content, with various nominal density: 500, 650 and 800 kg/m^3 (hereinafter called "panel type"), with use 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 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 panels have been 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 pictures of the raspberry particles used to produce the investigated panels are presented on figure 1. As it is shown, the particles of face layers (figure 1a) are of smaller slenderness, because the length to thickness ratio is smaller. The reason of such achieved particles shape can be quite high content of bark, since the stalks were not debarked prior to particles producing. The raspberry stalks bark is quite brittle, thus, the particles cutting lead to produce high amount of small, broken particles instead of desirable particles of higher length. In case of particles expected to use for particleboards core layer production (figure 1b), the particles are longer and the shape is more comparable to industrial particles.

Figure 1. The pictures of raspberry particles used in research to produce face (a) and core (b) layers of particleboards (source: own research)

The bulk density measurement results in relation to industrial particles bulk density, are presented on figure 2. In case of face layer particles, the industrial particles bulk density is about 21% higher that the density of raspberry particles. This difference should positively affect the mechanical parameters of produced panels, especially bending properties (bending strength, modulus of elasticity). Lower bulk density of particles used for particleboard production lead to higher densification of mat, what result in better connections between particles, less free spaces, more even density distribution, and due to this, better mechanical properties.

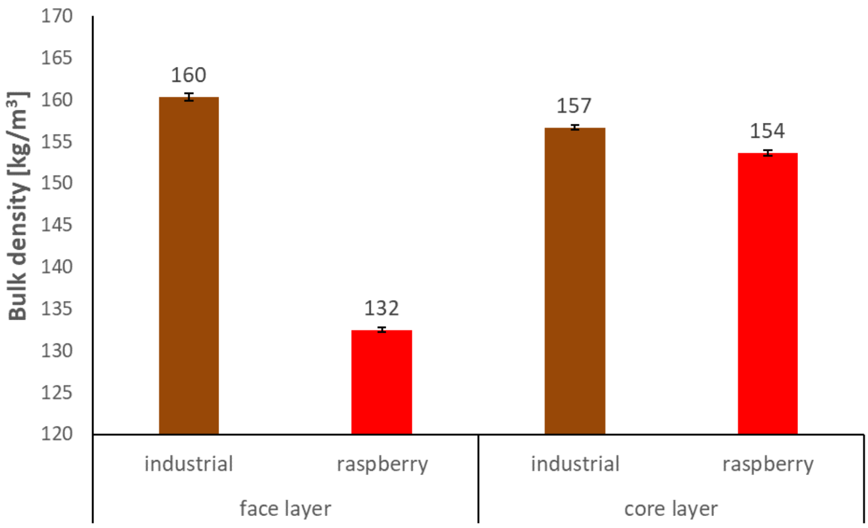

Figure 2. The bulk density of industrial and raspberry particles.

The results of measurement of modulus of rupture (bending strength) of the particleboards produced from raspberry stalks particles, in relation to panel density, are shown on figure 3. The measured values of modulus of rupture significantly increases with panel density increase from 4 N/mm^2 for 500 kg/m^3 dense panel to 14 N/mm2 for panel of density of 800 kg/m^3. It is worth to add that the minimum value of bending strength according to EN 312:2010 requirements for P2 panel type, 11 N/mm^2, has been meet with the raspberry particles particleboard density about 700 kg/m^3. Such conclusion can be formulated when analyze the regression line of the dependency of MOR on panel density. All the investigated mean values of bending strength are statistically significantly different. In case of modulus of elasticity results, which are presented on figure 4, the similar raise of the modulus of elasticity with the panel density can be observed. The minimum 1600 N/mm^2 MOE required according to above mentioned standard for P2 panel type, can be achieved by raspberry particleboards according to regression line examination, with the density about 680 kg/m^3.

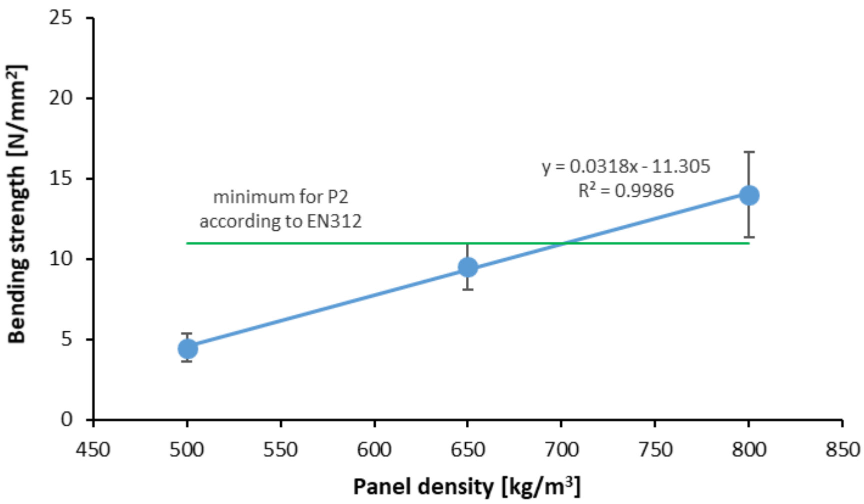

Figure 3. Influence of particleboards density on their bending strength.

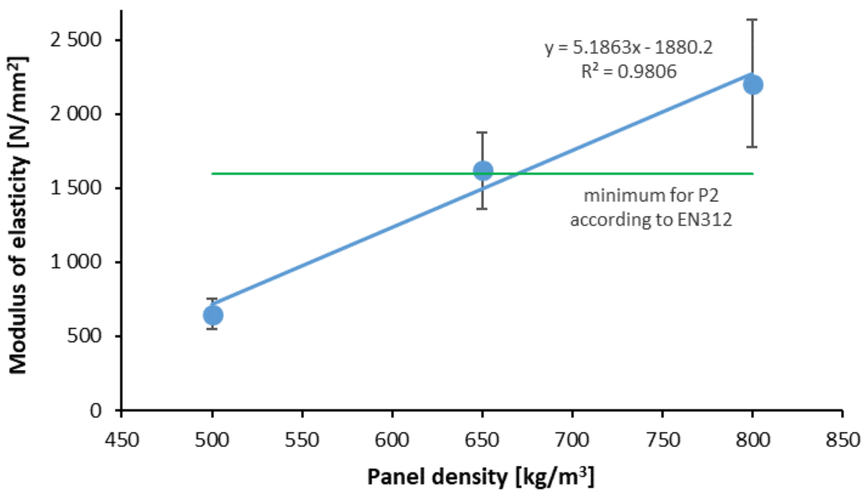

Figure 4. Influence of particleboards density on their modulus of elasticity.

The values of internal bond of the panels of various density, produced of raspberry stalks lignocellulosic particles, are presented on figure 5. The internal bond of produced panels significantly raises with the density increase. The lowest value of IB is 0.25 N/mm^2 and the highest value is 0.9 N/mm^2, for lowest and highest values, respectively. When analyze the presented regression line, it can be concluded, that the minimum IB value required according to EN 312:2010 standard for P2 type panels can be reached by raspberry particleboards with the density not lower that ca. 520 kg/m^3. All the presented average values of IB are statistically significantly different.

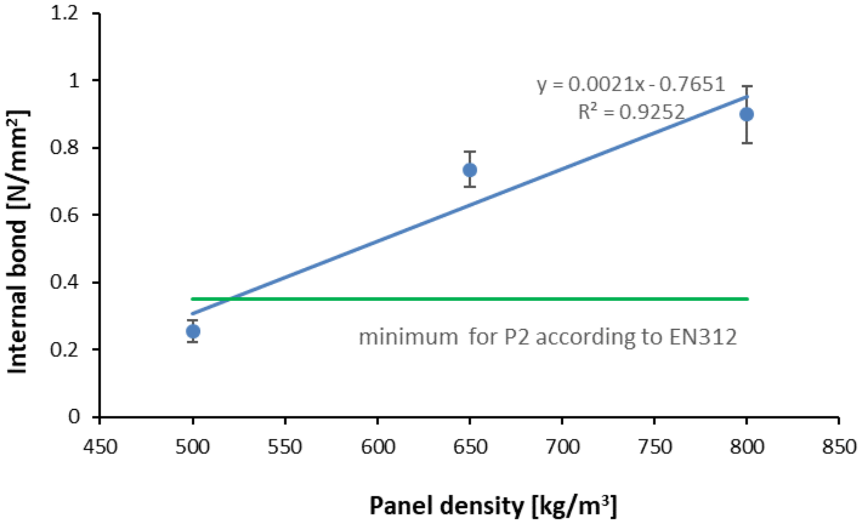

Figure 5. Modulus of elasticity of investigated panels.

The results of measurement of screw withdrawal resistance of the different density panels produced from raspberry particles are displayed on figure 6. According to presented data, the SWR significantly raises from 72 N/mm for the panels of density of 500 kg/mm^2 to 238 N/mm (over 330% raise) for panels of density of 800 kg/m^3. It mean that for every percent of panel density raise in measured range, the SWR growth is about 5.5%. It should be added that all the investigated mean values of SWR are statistically significantly different.

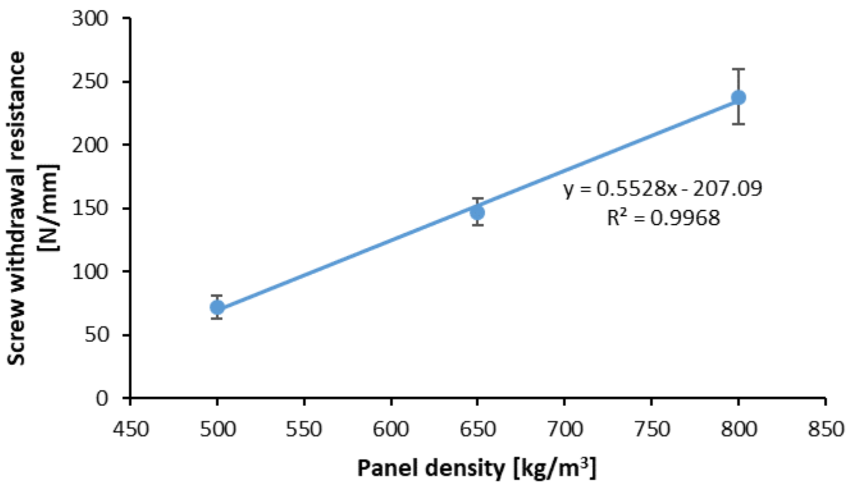

Figure 6. Screw withdrawal resistance of the tested panels of different density.

The values of physical properties of the tested panels of different density, produced from raspberry particles, like water absorption and thickness swelling, are presented on figure 7a and figure 7b, respectively. In case of water absorption, this feature values decrease with the panel density increase. The reason of this situation is density-induced reduction of empty spaces on panel structure, which can be potentially available by water to fill it. The opposite situation is in case of thickness swelling, where the thickness of the panel soaked in water increases with the panel density increase. This occurrence can be explained by the higher amount of lignocellulosic material, which is compressed during panel production, an can react with water and swell. It is worth to say that the differences between water absorption and thickness swelling, observed after 2 and 24h of soaking in water, are higher with the increasing panel density. All the registered values of water absorption and thickness swelling are statistically significantly different within the group of 2h and 24h of soaking.

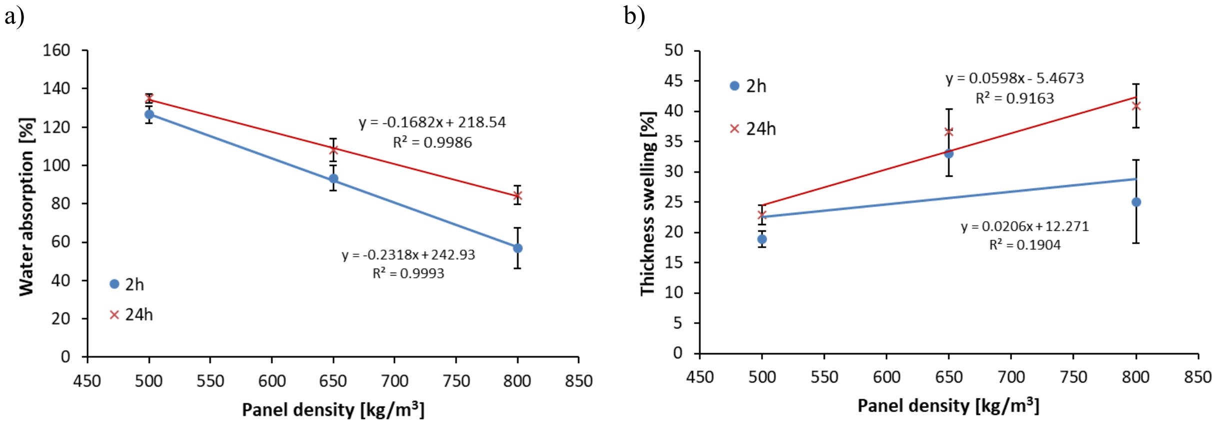

Figure 7. Water absorption (a) and thickness swelling (b) of tested panels of different density.

On the figure 8 the density profiles of particleboards of different density are presented. Due to the symmetrical shape, the profiles has been presented only for one side of the panels from the face to the middle of thickness. The shape of the profiles are characteristic for the particleboards, since the high density on the face layers and decreasing density towards the center of the panel thickness can be observed. It can be concluded that with the increased panel density the differences between density of face and core layers are more intense. Also, the effect of calibration of the panels is visible on the face layers due to the high gradient of the density.

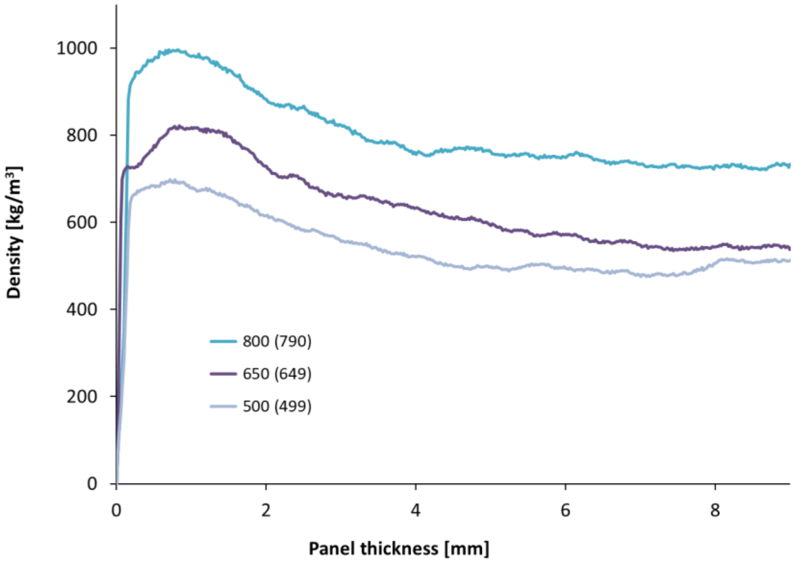

Figure 8. Density profiles of particleboards of different density.

CONCLUSIONS

According to the conducted research over influence of density of the particleboards made of raspberry lignocellulosic particles on the panels' properties, and the analysis of the achieved results, the following conclusions can be drawn:

1. There is higher mass fraction share of larger particles produced from lignocellulosic chips of raspberry, compare to industrial particles. This conclusion is representative for both, face and core layer particles.
2. The bulk density of raspberry particles is lower than of industrial particles, however, there is higher difference of bulk density in case of face layer particles.
3. The modulus of rupture and modulus of elasticity of the particleboards produced from raspberry lignocellulosic particles significantly increases when the panels density increase from 500 to 800 kg/m^3. However, in the light of European standards requirements for furniture particleboards, the minimum bending strength and modulus of elasticity can be reached over ca. 680 kg/m^3.
4. The internal bond of raspberry particles panels significantly increases with density increase, and minimum requirements of European standards for furniture panels are reached with the panel density about 520 kg/m^3.
5. The screw withdrawal resistance of different density particleboards made of raspberry significantly raises (over 3 times) when panel density grows from 500 to 800 kg/m^3.
6. The water absorption of raspberry panels decreases with panel density increase.
7. The thickness swelling of the tested panels grow with the panel density increase. The differences of the thickness swelling values are much more readable in case of higher density of panels.
8. The differences between face and core layers density are more visible when the density of panels grow.

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Streszczenie: *Wpływ gęstości na wybrane właściwości płyt wiórowych dla meblarstwa wytworzonych z cząstek lignocelulozowych maliny Rubus idaeus L.* Celem badań było określenie wpływu gęstości trójwarstwowych płyt wiórowych dla meblarstwa, wytworzonych w warunkach laboratoryjnych, przy trzech różnych gęstościach: 500, 650 i 800 kg/m^3, na ich wybrane właściwości mechaniczne i fizyczne. Dodatkowo scharakteryzowano skład frakcyjny oraz gęstość nasypową wytworzonych wiórów. Badania wykazały, że wraz ze wzrostem gęstości badanych płyt wiórowych we wspomnianym zakresie, następuje znacząca poprawa parametrów wytrzymałościowych płyt, jednak dochodzi również do niekorzystnego wzrostu spęcznienia. Zarysowują się również różnice w profilach gęstości badanych płyt.

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