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Selected physical and mechanical properties of particleboards with variable shares of nettle *Urtica dioica* L. lignocellulosic particles

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Abstract: *Selected physical and mechanical properties of particleboards with variable shares of nettle Urtica dioica L. lignocellulosic particles.* The aim of the research was to confirm the possibility of using woody particles of either young or adult nettle *Urtica dioica* stems as alternative raw materials in the production of particleboards. As part of the work, particleboards made out of nettle *Urtica dioica* particles were produced in laboratory conditions and selected physical and mechanical properties of the obtained boards were tested. The results show, that it is possible to manufacture particleboards for the furniture industry using particles of nettle (*Urtica dioica L.)* meeting the requirements for P2 boards according to EN 312 as long as nettle particle mass content does not exceed 50%.

Keywords: nettle; Urtica dioica L.; particleboard; furniture

INTRODUCTION

There is need for a change. Pressure regarding forest resources rises due to the high demand for wood and it is inevitable that at some point we need to find a better solution. Research is driven by growing interest in sustainable and eco-friendly alternatives to traditional building materials.

People are slowly becoming more and more conscious of the environmental impact associated with conventional furniture practices, which is why there is a continuous necessity of exploring novel, renewable, efficient solutions. Nettle *Urtica dioica* L., is widely available in the northern hemisphere, a rapidly growing plant, that has a lot of potential to become a contender for sustainable material development. Since it has been used since ancient times for the production of fabric similar to Cannabis sativa ssp. Sativa. During World War I it was used by the German army for clothing purposes since cotton was not available (Deepa et al. 2023). Many different appliances are starting to see daylight such as environment-friendly sound absorbers sourced from nettle fibres (Raj et al. 2020) or nettle and glass fiber-reinforced hybrid composites (Abbès et al. 2022). Previous attempts at creating boards from other alternative raw materials include hemp shives (Auriga et al. 2022), tomato stalks (Taha et al. 2018), olive stone and almond shell (Jerónimo et al. 2022), canola meal (Tene Tayo et al. 2022), Mauritia flexuosa and Eucalyptus spp. Wood (Faria et al. 2022), oat husk (Neitzel 2023), cotton stalk and corn (Kup and Vural 2021), leather shavings and waste papers (Kibet et al. 2022), sugarcane (Battistelle et al. 2016), poppy husk (Kucuktuvek et al. 2017), seaweed (Yushada et al. 2018), sunflower (Taş and Kul 2020), peanut and pinus oocarpa hulls (Brito et al. 2022), walnut and almond shells (Pirayesh et al. 2011). Previous studies on black chokeberry (Kowaluk and Wronka 2020), and tomato stalks (Taha et al. 2018), suggest that it is possible to successfully produce boards from alternative materials that meet European standards.

Wronka and Kowaluk (2022) may suggest that reducing dust fractions of material might improve resination. Apart from fibre source (Dowgielewicz 1954), the nettle stem can be a potential source of lignocellulosic particles, which can be processed and applied in lignocellulosic-based composites production. Thus, the aim of the research was to confirm the possibility of using woody particles of either young or adult nettle *Urtica dioica* stems as alternative raw materials in the production of particleboards.

MATERIALS AND METHODS

Raw material preparation and characterization

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

- Young (2-year plant; about 3 months of stems cultivation) nettle *Urtica dioica* stems moisture content (MC) of 8.2%±1%;
- Adult (5-year plant; about 8 months of stems cultivation) nettle *Urtica dioica* stems MC of 8.2%±1%;
- industrial usage particles (over 95% of *Pinus sylvestris* L. particles) for both mixing and reference values of particleboards, about 3% of MC;
- the commercial urea-formaldehyde (UF) resin (Silekol Sp. z o.o., Kędzierzyn-Koźle, Poland) of about 66.5% of dry content (EN 827 2005) with a molar ratio of 0.89 has been used;
- ammonium sulphate ((NH4)2SO4) water solution hardener.

The nettle stems have been mechanically cut onto ca. 50 mm long chips, and these chips have been milled in a laboratory 3 knife drum mill with an outlet fitted with 6x12 mm^2 mesh to the form of particles. All the particles of nettle have been dried to the MC of about 3% and then were sorted into the following fractions:

- core layer particles, which pass the 8 mm mesh and retain on the 1 mm mesh
- face layer particles, which pass the 1 mm mesh and retain on 0. 1 mm mesh

The achieved particles, as well as industrial particles, have been characterized by measuring mass fraction share. The following sets of mesh have been applied: 0.25, 0.5, 1, 2, 4 and 8 mm. Two measurements have been completed on both young and adult nettle particles. The bulk density of the particles used in the research was tested, as well. For both the face and core layer, varied by young and adult variants two individual measurements were carried out.

Particleboard production

A 16 mm – thick three-layer particleboard, with face layers weight share of 32%, nominal density of 700 kg/m^3 and various weight shares of nettle lignocellulosic particles of 0%, 10%, 25%, 50% and 100%, with use industrial coniferous particles and urea – formaldehyde (UF) resin, were produced in laboratory conditions. The resination of particles was 12% and 10% for the face and core layers, respectively. The curing time of glue mass at 100°C was about 82 s. No hydrophobic agent was added during panel production.

The pressing parameters were as follows: temperature 200°C, time factor 20 s/mm, maximum unit pressure 2.5 MPa (which was periodically reduced to steam release). As a reference, the industrial particles have been characterized and used to produce the panels in laboratory conditions, as mentioned above. All the tested panels have been conditioned before the tests in 20°C/65% ambient air to constant mass and then were calibrated to nominal thickness by double-side mechanical sanding.

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 1993), tensile strength perpendicular to the plane of the board (internal bond, IB) (EN 319 1993), screw withdrawal resistance (SWR) (EN 320 2011). A number of 10 samples of every panel type were used for mentioned tests. Before the testing, the density of every single sample was measured (EN 323 1993).

According to the results, the maximum measured difference between the 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 water immersion (EN 317 1993) standard (10 samples were used, each with dimensions 50 x 50 mm^2 for every variant). The samples were measured and weighed after 2 and 24 hours of soaking. Density profile analysis was carried out with the use of 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.

Statistical analyses

Analysis of variance (ANOVA) and t-tests calculations were used to test ($\alpha = 0.05$) for significant differences between factors and levels, and where appropriate, using IBM SPSS statistic base (IBM, SPSS 20, Armonk, NY, USA). A comparison of the means was performed by the ANOVA test. The statistically significant differences in achieved results are given in the Results and Discussion paragraph whenever the data were evaluated. Where applicable, the mean values of the investigated features and the standard deviation indicated as error bars, were presented on the plots.

RESULTS AND DISCUSSION

The results of the measurement of the mass fraction share of the particles used in research to produce the panels are presented in figure 1. Both variants of nettle have a significantly higher content of <0.25 mm; 0.25 mm and 0.5 mm particles, compared to industrial. Adult nettle values for <0.25 mm mesh could suggest that woody parts produce more dust in the process of milling. As of 1 mm fraction, there is still a disproportion between nettle and industrial. Particles on 1 mm mesh make up almost 40% of both young and adult variants. In the case of industrial 1 mm, 2 mm and 4 mm each equally contain about 30% material, which combined gives us over 90% of the entire particle content. Nettle in comparison to industrial contains fewer particles from 2 mm and 4 mm mesh and their percentages are similar in both variants.

The graph in figure 2. shows the bulk density of nettle compared to industrial particles. Industrial particles have higher bulk density due to lower loose fibers content. Adult particles show lower bulk density in both the face and core layer. The bulk density difference between layers is proportional. Those values may explain the obtained results of the modulus of rupture and modulus of elasticity mentioned later.

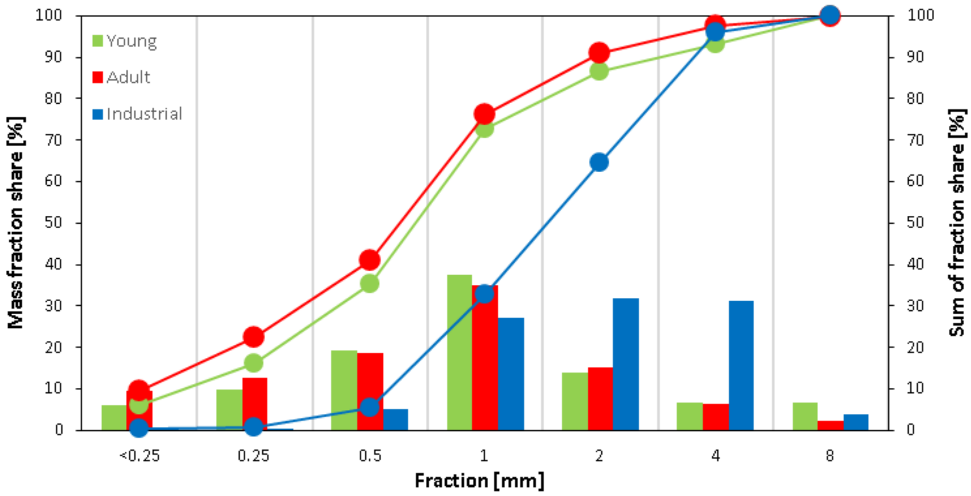

Figure 1. The mass fraction share of young nettle, adult nettle and industrial particles used in the production of particleboards

Similar findings regarding the differences between alternative and industrial raw material particles' bulk density have been found when investigating raspberry lignocellulosic particles applied in particleboard production (Wronka and Kowaluk 2019a).

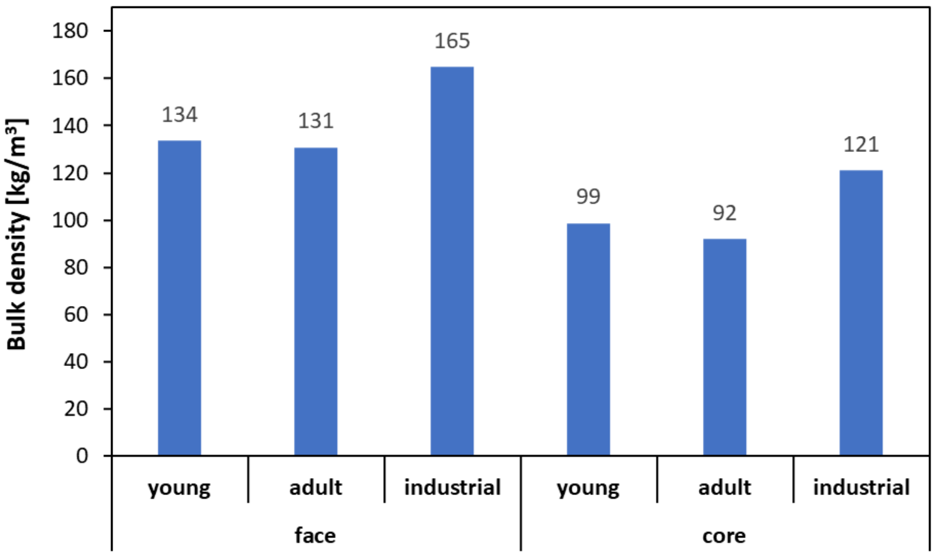

Figure 2. The bulk density of investigated panels particles

The graph (figure. 3) shows values obtained for the modulus of elasticity of the nettle panels. There is a decrease in values of the elastic modulus proportional to the increase in the share of nettle particles. Adult sample values decline at a steady rate, while young ones differentiate more. Samples with 10% content of young nettle present the highest values out of all tested variants. In contrast, a 5% sample of the same variant shows much lower MOE. Despite the decreasing tendency, all variants besides the 100% young variant conform to the P2 type panel (EN 312 2010). All the achieved average MOE results, when referred to another in the range of the same raw material (young or adult) are statistically significantly different one from another.

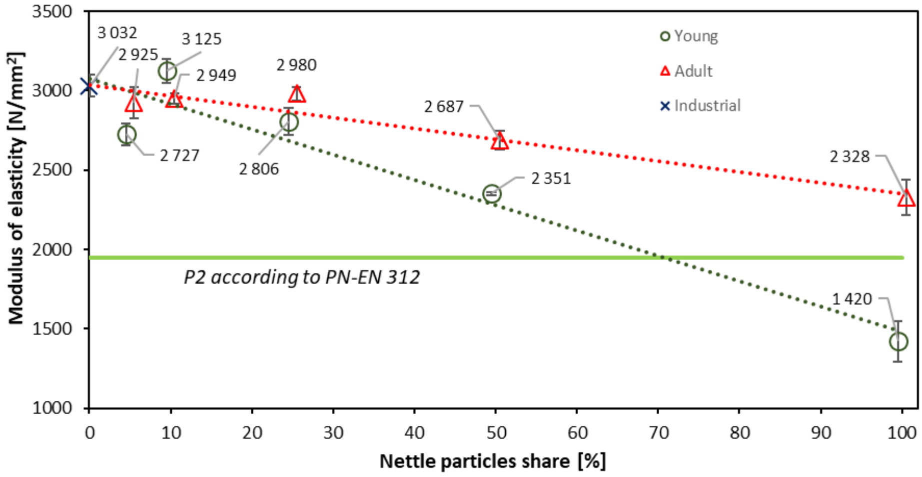

Figure 3. Modulus of elasticity of investigated panels with various shares of nettle particles

The graph shown in figure 4 displays the influence of share in nettle particles on the modulus of rupture of the boards produced. An increase in the share of nettle particles causes a decrease in MOR. The highest values are reached by 0% and 10% young nettle ratio. There is a significant decline in strength in 0% to 5% samples which steadily continues through adults and is more rapid for young samples. All variants until 50% share of nettle conform to the requirements for P2 type panels (EN 312 2010). This finding has been also confirmed in the case of particleboards made of raspberry stem wooden particles (Wronka and Kowaluk 2019b).

Regarding the statistically significant differences in mean values of MOR, in the case of the adult nettle particle panel, there were statistically significant differences between the group of 5%, 10% and 25% panels against 50% and 100%; all the achieved MOR results achieved for young nettle particles were statistically significantly different one from another.

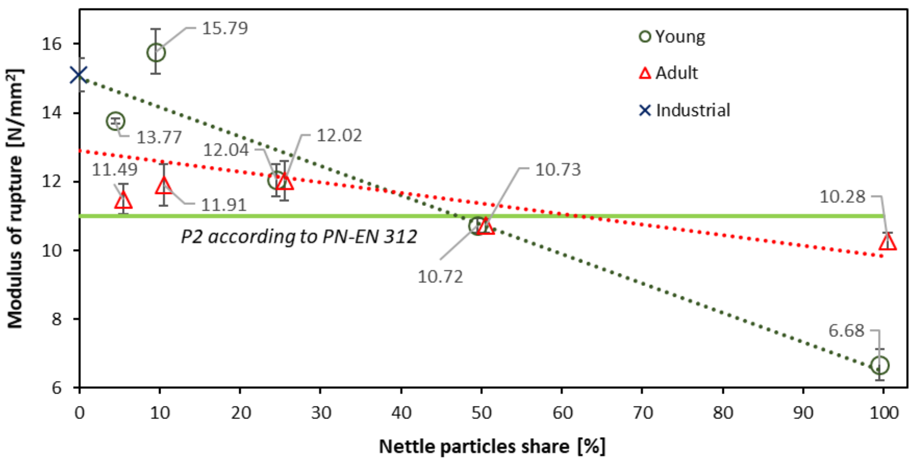

Figure 4. Modulus of rupture of investigated panels with various shares of nettle particles

The values of the internal bond are shown in figure 5. The highest values of IB belong to the reference panel. The adult variant displays a rising tendency while having the lowest IB values in the graph at 10% nettle share. The highest values have been reached by 25% young nettle variant. In pure nettle panels, there is a significant difference between adult and young samples, the first one being close to reference particleboard and the second obtaining the second lowest value. This phenomenon might be caused by the share of fibrous fraction or its different structure in young nettle. While producing the boards fibres would cluster into agglomerates that were harder for the glue to penetrate which caused reduced resination in affected areas. The alignment of those weak points in particleboard might have been a cause of reduced strength in young nettle panel variants. It is worth mentioning that all the tested panels have met the requirements for P2-type panels (EN 312 2010).

There were no statistically significant differences between the variants 5% and 50% in the case of adult nettle panels, and between 5% and 10%, when referred to 100% and 50%, respectively, for young nettle panels.

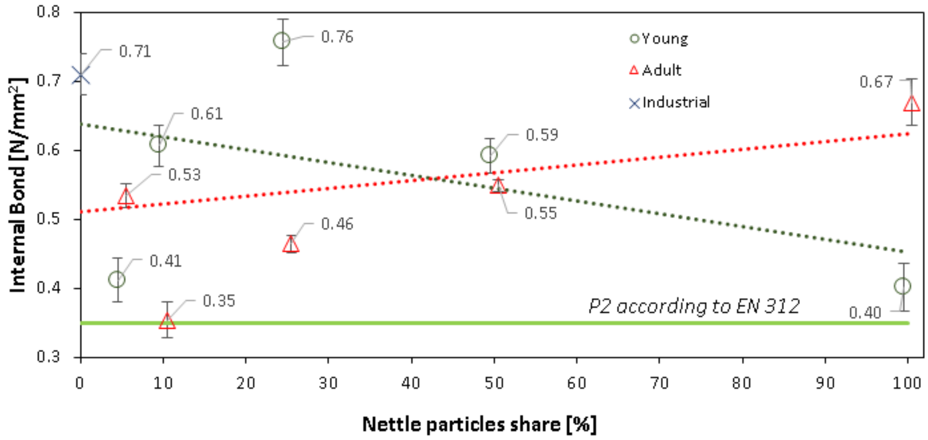

Figure 5. Internal bond values of investigated panels with various shares of nettle particles

The graph shown in figure 6. depicts the thickness swelling results of the individual particleboard variants. The swelling decreases with the increase in adult nettle particle share and increases with the rise of young nettle particle participation. Previous studies on medium-density fibreboards (Akgül 2013) made out of nettle do not comply with our results. Thickness swelling in MDF is rising with an increasing share of nettle, which may suggest that the declining trend regarding the adult variant might be caused by the difference in shares of woody particles and not the fibres in different growth stages of nettle plants.

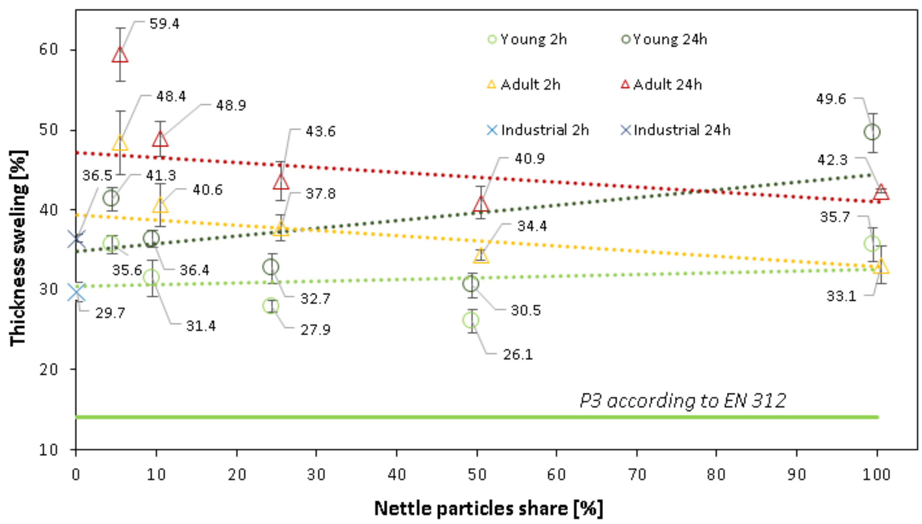

Figure 6. Thickness swelling of investigated panels with various shares of nettle particles

The only statically significant differences have not been found for the 50% and 100% nettle variants both after 2 h and 24 h of soaking, for young and adult nettle particles. That might be caused by higher density in the core layer as shown in figure 9. There was no addition of hydrophobic agent in the making of those particleboards which may result in them not meeting requirements for P3 furniture board standards (EN 312 2010). The attached diagram (figure 7.) depicts values of water absorption of manufactured particleboards. Measurements were taken after 2 and 24 hours of water immersion time. It can be concluded from the graph that the water absorption trend is inclining with the rise of nettle particles used in all variants besides adult 2h. The highest mean swelling percentage is seen in 100% of young nettle panels after 24h. The same variant after 2h of soaking expressed a lower WA percentage than an adult at 5, 25 and 50%. The values for adult nettle are much more consistent than young nettle.

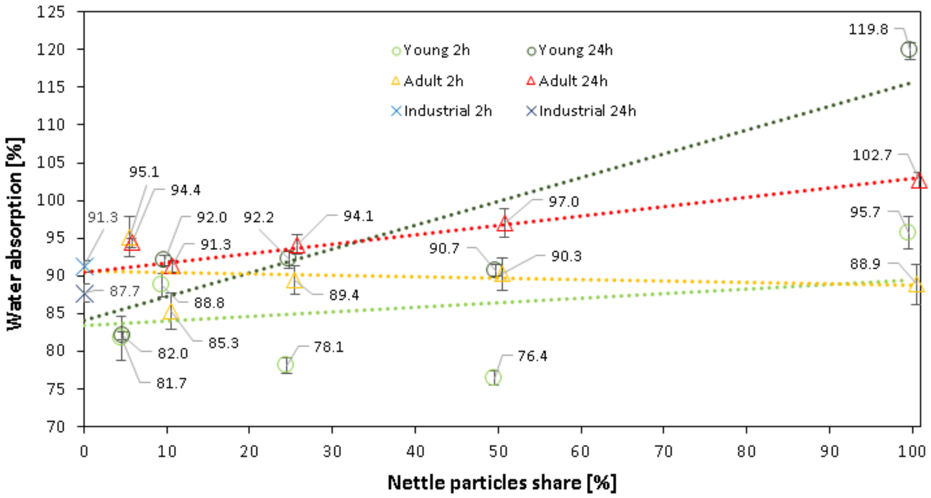

Figure 7. Water absorption of investigated panels with various shares of nettle particles

The graph shown in figure 8. displays resistance values for screw withdrawal. There is a decline in resistance proportional to an increase in nettle share regarding both variants of samples with emphasis on young nettle which obtains higher values than adults for 0-50% nettle content and then drastically declines at 100%. The highest value also belongs to young nettle at 10% share of particles which exceeds the reference panel by close to 10 N/mm.

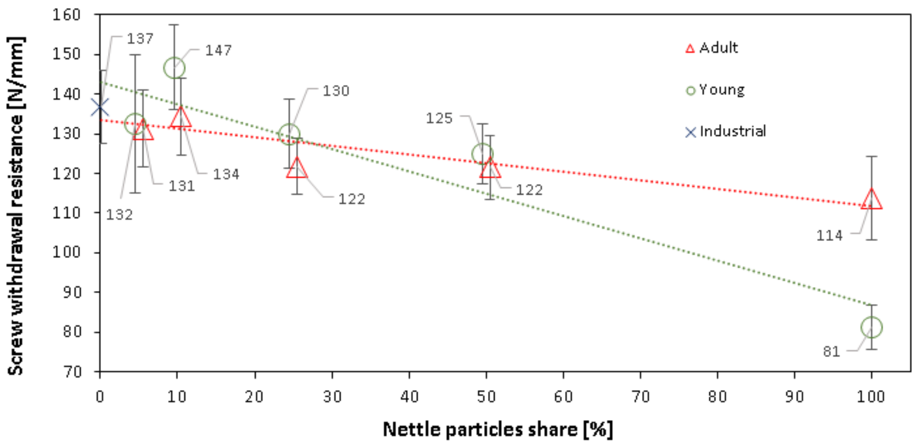

Figure 8. Screw withdrawal resistance of investigated panels with various shares of nettle particles

The only statistically significant differences between average values of SWR for nettle particleboards have been found only for young particles between 100% panel when referred to remaining young nettle particle panels, as well as between 50% when referred to 100% and 10% panels. The obtained result is similar to black chokeberry particleboards where with the increase of chokeberry screw withdrawal resistance also declined (Kowaluk and Wronka 2020).

The density profile (half of the thickness) is shown in figure 9. It can be seen that the shapes of density profiles correspond to the general trend visible in all particleboards due to their varied layer nature. The face layer has a much higher density and is made out of smaller fraction particles with higher resination values. Core layer particles are bigger and have lower resination values which translate to lower density. Raise in share of nettle particles in all combinations but 100% young have quite similar density profile to reference industrial board. Pure young nettle particleboard has a much lower face layer density that correlates with higher core layer values. However, the same panels had significantly higher density in the core layers. This might contribute to lower MOR and MOE values obtained since the density of face layers is responsible for these parameters during bending.

The higher density in the core layer caused a much higher IB of the panels made in 100% of young nettle particles. This trend is similar to one obtained in the study made on panels with a share of black chokeberry particles (Kowaluk and Wronka 2020).

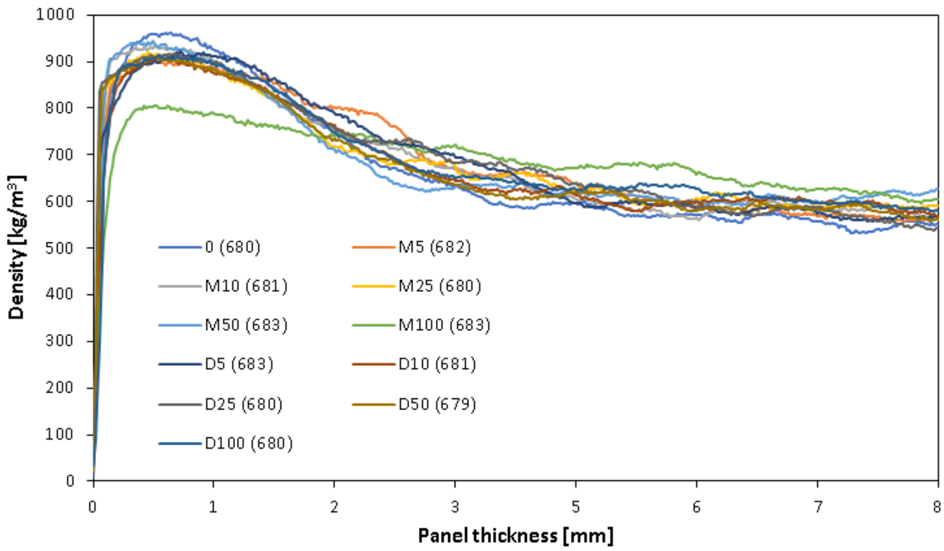

Figure 9. Density profile of investigated panels with various shares of nettle particles (from surface to the middle of thickness)

CONCLUSIONS

According to the research and analysis of the obtained results, the following conclusions have been drawn:

1. The modulus of rupture and modulus of elasticity of produced panels decreases with an increase in nettle particles share.
2. The internal bond values for:
   - adult variant is in decline from 5 to 10% and then rises with higher percentages
   - young variants are increasing from 5 to 25% and then decline from 50 to 100%.
3. The thickness swelling of the panels for:
   - the adult variant is declining with the increase of nettle particles
   - the young variant is increasing with the increase of nettle particles
4. The water absorption of tested particleboards is increasing with the share of nettle particles.
5. The screw withdrawal resistance of tested particleboards decreases with an increase in nettle particle content.

6. The density profile values are similar to reference values with the exception of the 100% young variant which shows much lower density in the face layer.
7. In order to meet the requirements of European standards for furniture panels, three-layer particleboards with 700 kg/m^3 made with nettle *Urtica dioica* must contain less than 50% of nettle particles (due to the modulus of rupture criterion).

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Streszczenie: *Wybrane właściwości fizyczne i mechaniczne płyt wiórowych o zmiennym udziale cząstek lignocelulozowych pokrzywy Urtica dioica L.* Celem badań było potwierdzenie możliwości wykorzystania zdrewniałych cząstek młodych lub dorosłych łodyg pokrzywy *Urtica dioica* jako alternatywnego surowca do produkcji płyt wiórowych. W ramach pracy wytworzono w warunkach laboratoryjnych płyty wiórowe z cząstek pokrzywy *Urtica dioica* oraz zbadano wybrane właściwości fizyczne i mechaniczne otrzymanych płyt. Uzyskane wyniki wskazują, że możliwe jest wytwarzanie płyt wiórowych dla przemysłu meblarskiego z cząstek pokrzywy (*Urtica dioica* L.) spełniających wymagania dla płyt P2 wg EN 312, o ile udział masowy cząstek pokrzywy w płycie nie przekracza 50%.

Słowa kluczowe: pokrzywa; *Urtica dioica* L.; płyta wiórowa; meble

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