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Influence of the content of recycled artificial leather waste particles in particleboards on their selected properties

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Abstract: *Influence of the content of recycled artificial leather waste particles in particleboards on their selected properties.* Artificial leather is a layered fabric-plastic composite that resembles natural leather in appearance. Due to its wide range of advantages, artificial leather is widely used as an upholstery material in the renovation and production of furniture or even car upholstery. The aim of the research was to manage upholstery leather waste by adding previously shredded particles of artificial leather of different contents (5, 10, 25 and 50% by weight) to particleboard. Tests of selected mechanical properties (bending strength and modulus of elasticity and resistance to screw withdrawal) and physical properties (density profile, thickness swelling after immersion in water) were completed. It can be concluded that, depending on the further use of the board, there is a possibility of using the recovered artificial leather particles as a reasonable addition to wood fibres in the production of particleboard.

Keywords: recycling, particleboard, artificial leather, upholstery furniture, circular economy

INTRODUCTION

Recycling artificial leather from furniture is an important step towards the sustainable use of these materials and reducing environmental impact. Among the scientific publications available, there are few examples of the re-use of artificial leather in furniture manufacturing technology, and if they exist they are usually laboratory trials, unfortunately not implemented in mass production. Leather waste is most often landfilled and its disposal is not immediate, so various attempts are being made, mainly to shred leather waste, which is easier to reuse (Usenbekov et al. 2021). Tests include the use of leather offcuts and waste paper. Various ratios of leather to paper were used: 100:0, 25:75, 50:50, 75:25. The research confirmed the possibility of using leather and paper as an alternative raw material in single-layer particleboard technology - the quality of the strength properties is mainly influenced by the resin content and the mix ratio. The resulting boards can be used in interior applications or for interior decoration (Kibet et al. 2022). Leather cuttings, paper mill residues and natural polymers are used to produce substitute leathers. The properties of which are very similar to those of the original raw material, i.e. natural leather (Senthil et al. 2023). Another way of utilizing artificial as well as natural leather is to produce low-cost bricks that contain, among other things, solid waste and powdered leather. Compared to clay fillers, bricks that contained leather in their composition had better strength properties (Senthil et al. 2022). Another example of the use of leather scraps is a composite consisting of leather fibres, nitrile rubber and polyamide fibre. With the increase of the polyamide fiber in the composite, its strength properties increase. This is another proof that leather cuttings can be used as a filler in composites (Hang et al. 2023). Another leather application is to use as an ingredient in self-compacting concrete, which has worked well for natural leather (Thakre and Rajak 2022).

For both natural and artificial leather, the problem of production waste arises, which should be used if we do not want to generate unnecessary waste. Natural leather can be recycled into biofuel (Wrzesińska-Jędrusiak et al. 2023) because leather recycling requires the removal of compounds such as chromium (Mwondu et al. 2021), but for artificial leather, the process is more complicated - it requires chemical intervention such as pyrolysis (Xu et al. 2022). The leather recycling process itself is complicated because the final leather product is secured for use distinctively - its finishing requires agents that emit volatile organic compounds and toxic cross-linking agents as well as resins that are not biodegradable. So far, studies have been carried out that confirm the possibility of eco-friendly leather finishing - this means that its further use through recycling will not increase the harmfulness of the new product (Gargano et al. 2023). An opportunity for the leather market in furniture manufacturing is vegan leather made from agricultural waste such as maple leaves and apple pulp, which has been blended with additives such as kombucha biomass cellulose and biodegradable polyesters and plasticizers. Other natural alternatives include a material made from pineapple leaves that have been converted into a non-woven fabric and then coated with polylactic acid (Hoque 2017). The simple biodegradable composition may carry great potential for recycling such composites (Saha et al. 2020). Another alternative, not yet considered in the context of artificial leather, is the production of materials similar to textile and starch composites, as it is done from used materials (Wang et al. 2023). Research carried out around the world confirms that the furniture waste market and public awareness should be focused on developing recycling networks, improving the quality of furniture and trying to sell or donate furniture to those in need before it ends up in the landfill. Such actions will contribute to reducing waste and also protect the environment from litter (Xiong et al. 2022).

The aim of the research was to manage upholstery leather waste by adding previously shredded particles of artificial leather of different contents (5, 10, 25 and 50% by weight) to the core layer of particleboard.

MATERIALS AND METHODS

Materials

Industrial particles of pine *Pinus sylvestris* L. with a moisture content (MC) of about 4% for the production of the face and core layers of 3-layered particleboard, obtained from a plant located in Poland, were used. The MC of the particles was about 3%. Industrial urea-formaldehyde (UF) resin Silekol S-123 (Silekol Sp. z o.o., Kędzierzyn-Koźle, Poland) with a dry matter content of about 65%, pH of 9.6, viscosity of 470 mPa s , with 2% dry matter aqueous ammonium nitrate solution as a curing agent was used as a binding agent to achieve a curing time of about 85 s for the adhesive mass at 100°C. Waste artificial upholstery leather (BHM Sp. z o.o., Chełm, Poland), consisted of polyester fabric covered by a layer of plasticized polyvinyl chloride, shredded manually into smaller (ca. 30 mm x 30 mm) particles and then milled in a knife mill with 6 x 12 mm^2 screen.

Production of the panels

Panels with dimensions of 320 mm × 320 mm and a nominal density of and thickness of 16 mm were produced. The core (68% by total panel weight) and face layer particles were mixed with the adhesive mass separately in a laboratory adhesive mixer. In the case of fine mixtures and fibres for the surface layers, these materials were mixed with the adhesive mass. Pressing was carried out with a hot press (AKE, Mariannelund, Sweden) at a pressing temperature of 200°C, a specific pressure of 2.5 MPa and a pressing factor of 20 s/mm of nominal panel thickness. After pressing, the panels were not calibrated (by grinding). The panels were 3-layered and differed in the content of particles of artificial leather in the core layer. Samples were produced with a mass proportion (referred to as the total panel weight) in the inner layer of 0, 5, 10, 25 and 50% content of artificial leather particles. Before the tests, the panels were conditioned at 20°C/65% relative humidity within 7 days.

Characterization of the panels

In this research, the following physical and mechanical properties were determined according to European standards (wherever available): density (EN 323), bending strength (modulus of rupture - MOR) and modulus of elasticity (MOE) (EN 310), internal bonding (IB) was determined according to EN 319, screw withdrawal resistance (SWR) (EN 320), water absorption (WA) and swelling thickness (TS) after 2 and 24 hours of immersion in water (EN 317). All mechanical properties were tested on a computer-controlled universal testing machine (Research and Development Centre for Wood-Based Panels Sp. z o.o. Czarna Woda, Poland). No less than 8 samples of each type of panel were used for each test of mechanical and physical parameters. To determine the density profile (DP), test specimens cut into 50 mm × 50 mm dimensions were used and analysed on a Grecon DA-X measuring instrument (Fagus-GreCon Greten GmbH and Co. KG, Alfeld/Hannover, Germany) with direct X-ray densitometry scanning panel thickness in 0.02 mm sampling step. Three samples from each test variant were examined, but one representative density profile for each panel type was selected for further evaluation. The selected results were referenced to the European standard (EN 312) where possible.

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

Determination of Modulus of Elasticity in Bending and of Bending Strength

Figures 1 and 2 show, respectively, the dependence of the modulus of rupture and modulus of elasticity on the content of artificial leather particles. It can be seen that both the bending strength and modulus of elasticity decrease with increasing material content. For the reference sample, the value of MOR is 12.7 N/mm^2, and for 50% artificial leather particle content it is already only 5.7 N/mm^2. As in the case of MOE (Fig. 2), the best result for MOR (disregarding 0% samples), showed a sample with 5% leather particle content (12.4 N/mm^2).

The lowest MOE value occurs for the highest artificial leather particle content - 952 N/mm^2 for a leather particle content of 50%. The highest MOE (3212 N/mm^2) is for the reference sample (0% content). On the other hand, when analysing samples with non-zero leather content, the highest MOE (2927 N/mm^2) was obtained for the sample with 5% leather particles. The statistically significant differences of mean MOR values have been found for 0% and 5% when refereed to remaining panels, as well as for 50% samples when referred to remaining samples. In the case of MOE, statistically significant differences have been found for 10% panels when referred to 0% and 50%, and for 5% panels when referred to 25% and 50% panels.

The MOE for a board with 10% leather content was 2485 N/mm^2, whereas Oliveira et al. (2021) studied the effect of leather fibres on particleboard at 10% fibres content and obtained results of 1714.5 N/mm^2. Barbu et al. (2020) produced particleboards using hazelnut and walnut shells bonded with various resins. The maximum MOE for a hazelnut panel bonded with MUF is 1790 N/mm^2, while the highest modulus of elasticity for a walnut panel bonded with the same resin is 1960 N/mm^2. The modulus of rupture for these samples came out to be 5.47 and 6.53 N/mm^2 respectively. Kibet et al. (2022) investigated the mechanical properties of a particleboard consisting of waste leather shavings and waste paper mixed with unsaturated polyester. The boards were varied by resin content and leather/paper ratio. The highest MOR result (14.3 N/mm^2) was obtained for a board with 60% resin content. Equally for MOE, the highest result was obtained for a panel with 60% resin content - 5030 N/mm^2. Despite the downward trend in the MOR and MOE results, the values of modulus of rupture meet the requirements of European standard (EN 312) with artificial leather particle content less than 10%, and in the case of MOE – the leather particle content should not exceed about 33%.

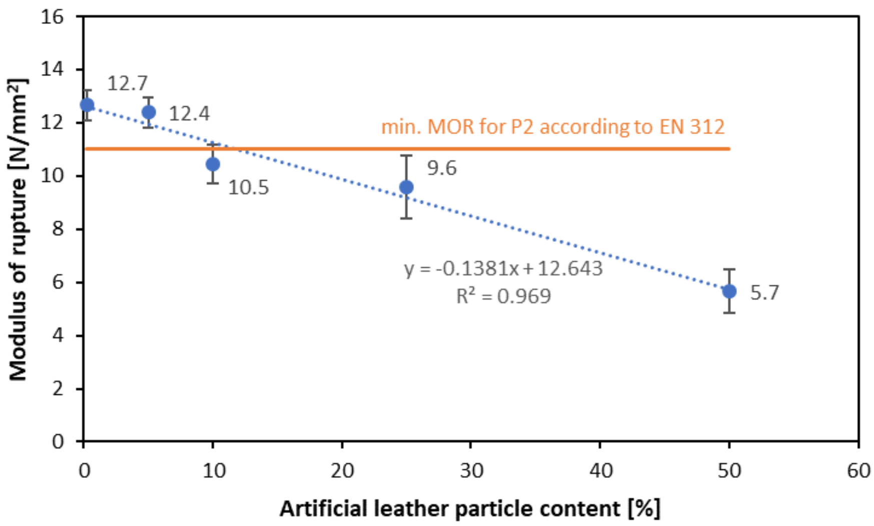

Figure 1. Influence of the artificial leather particle content on the MOR of produced particleboard

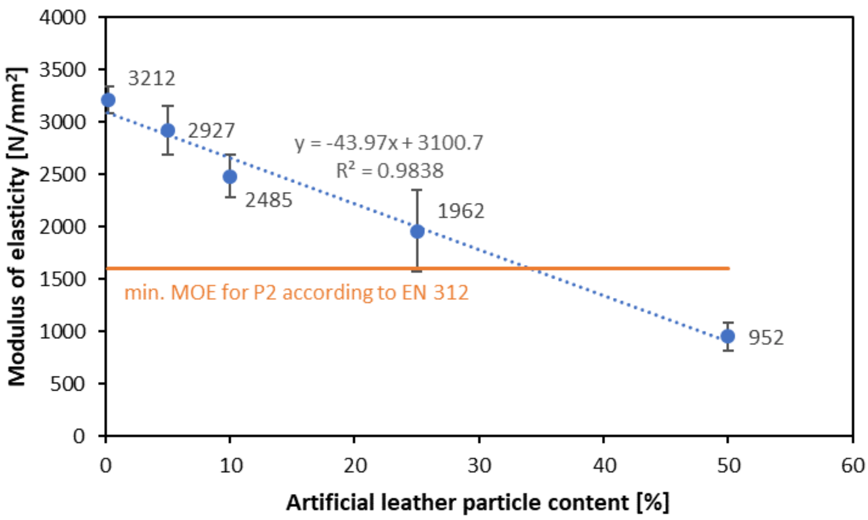

Figure 2. Influence of the artificial leather particle content on the MOE of produced particleboard

Screw withdrawal resistance

The results of screw withdrawal resistance measurements are shown in Figure 3. In the case of these tests, there is a downward trend in the average values as the proportion of artificial leather increases. The decrease in values between boards with the content of particles of artificial leather from 5 to 10% is 7 N/mm, while between panels with a material content of 10 to 25% the difference is 18 N/mm. For 50% content of leather particles, SWR is 49 N/mm, and for 0% it is 132 N/mm. The statistically significant differences in mean SWR values have been found for 0% samples when referred to remaining panels, as well as for 50% samples when referred to remaining samples, and, for 25% samples when referred to 5% panels.

The screw withdrawal resistance of selected commercial particle boards of different thicknesses (16 mm, 18 mm, and 25 mm) was tested by Yunus et al. (2019). The ratio of particle boards was 60% rubber wood and 40% mixed tropical wood with dimensions of 60 cm x 120 cm x board thickness. The highest SWR was obtained for the 16 mm board – 510 N/mm, while the lowest SWR of 471 N/mm was obtained for the 18 mm thick panel.

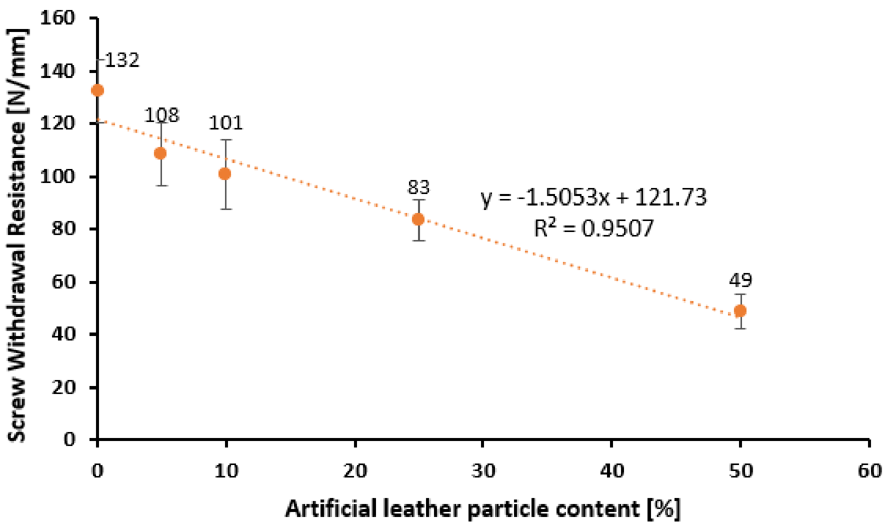

Figure 3. Screw Withdrawal Resistance of the panels with various content of artificial leather particles

Internal Bond

The results of the internal bond test of the effect of the content of particles of artificial leather on the internal bond of the fabricated panels are shown in Figure 4. The results show that an increase in the proportion of leather causes a decrease in IB, starting from 0.34 N/mm^2 for variants 5 and 10% to 0.12 N/mm^2 for the 50% variant. The IB for the 0% reference panel was 0.56 N/mm^2. The IB values of 0%, 5% and 10% were above or close to the requirements of EN 312. The statistically significant differences in mean IB values have been found for 0% samples when referred to remaining panels, as well as for 50% samples when referred to remaining samples, and, for 25% samples when referred to 5% panels.

A similar relationship was obtained by (Suchorab et al. 2023) where IB decreased in particleboard as the proportion of fabric fibres increased. A study was published that examined the addition of recovered HDF (HDF-r) fibres during HDF production Sala et al. (2020) for 10% HDF-r content, the IB value was 0.61 N/mm^2. Compared to the values in the reference panel, the IB decreased by almost 50%, and as for 0% HDF-r content, the IB value was 1.15 N/mm^2.

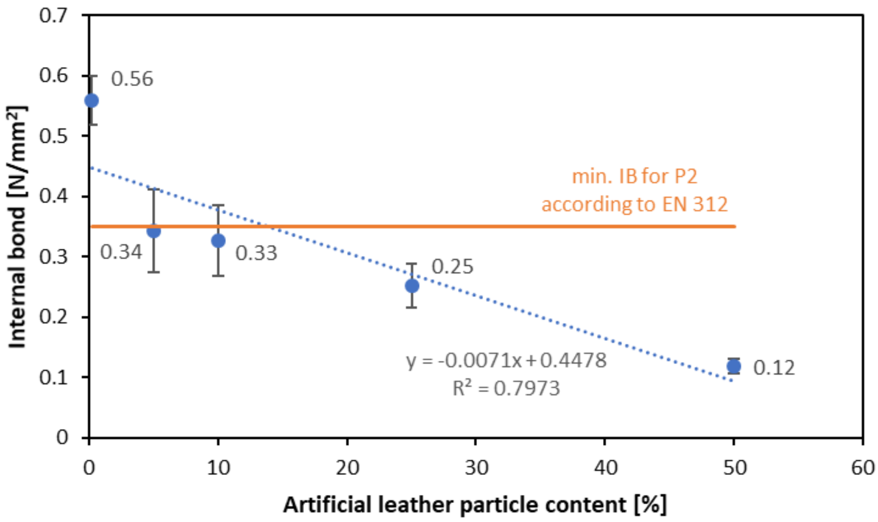

Figure 4. Internal Bond of the panels with various content of artificial leather particles

Thickness swelling and water absorption

The results of swelling and water absorption are shown in Figures 5 and 6, respectively. After 2 hours of immersion in water, the intensity of the swelling thickness results was more pronounced for increasing the content of the artificial leather particles than for 24 hours of soaking. After two hours for 0% slabs, the value of thickness swelling was 41.7, and for 50% content, it was 18.4%, a decrease of as much as 23.3%. After 24 hours of soaking for the 0% content, the swelling value per thickness was 47.1%, and for the 50% content, it was 20.1%, a decrease of 27%. The only statistically insignificant differences of mean TS values have been found for 5% samples when refereed to 10% panels.

In the production of three-layer particleboard with sunflower hulls, (Borysiuk et al. 2020) obtained significant water absorption only after 24h soaking in water. The thickness swelling after 2 and 24h increased by 12.4 and 30.6%, respectively. In particleboard tests with different textile (cotton) dust contents, the TS after 24h increased from 18.7% to 26.7% when the dust content increased from 0% to 40% in the middle layer (Nemli et al. 2019). Therefore, TS was adversely affected by the addition of textile dust to the middle of the particleboard. It can be seen that the maximum thickness swelling of the tested panels specified by European standards was exceeded. It can also be concluded that thickness swelling decreases as the particles of artificial leather increase.

The results of water absorption of the tested panels with different contents of particles of artificial leather are shown in Figure 6. It can be seen that as the leather content increases, the absorption decreases. For the sample with 0% leather content after 2 hours, the WA was 93.9%, while for the 50% panel, it was 79.9%, a decrease of 14%. After 24h immersion in water for the 0% content, the soaking ability was 100.1%, and for the 50% content, it was 86.1%. The only statistically significant differences of mean WA values have been found for 0% samples when referred to remaining panels, as well as for 5% and 10% samples when referred to remaining panels, and, for 50% samples when referred to remaining samples.

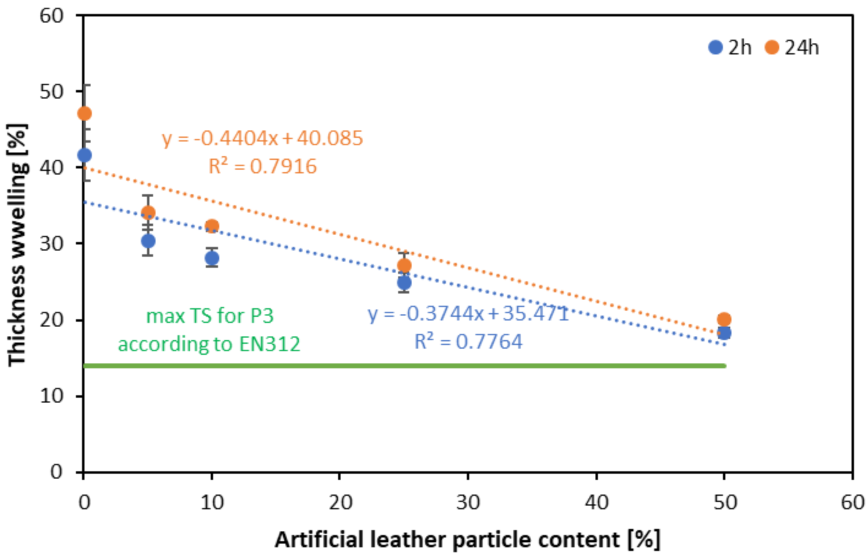

Figure 5. The Thickness swelling of the panels of various content of artificial leather particles

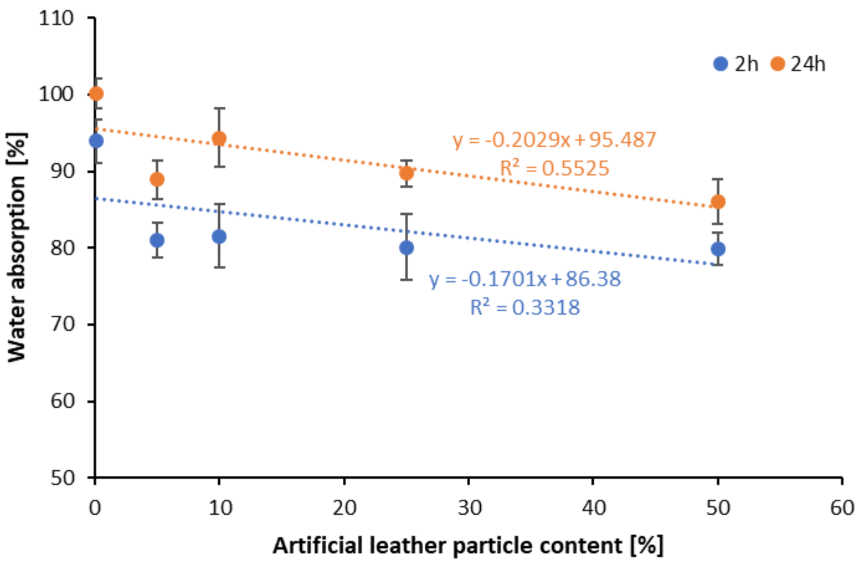

Figure 6. Water absorption of the panels produced with the use of different amounts of artificial leather particles

Density profile

The results of the density profile are shown in Figure 7. For the 0% variant, the graph looks standard - the face layers are more dense compared to the core layer. The graph showing the density profile of a particleboard containing 5% artificial leather additive has an overall outline similar to the standard density profile of particleboards, but the addition of leather causes irregular variations in the profile - justified by the much lower density of leather compared to wood. As the proportion of artificial leather increases, the deviations of the graphs are more chaotic and irregular, in the case of a proportion of 50% the density of the panel is higher in the core layers than in the face layers. Similar findings regarding irregularity of the density profile of the composite with a significant content of textile recycled materials have been found by Suchorab et al. (2023).

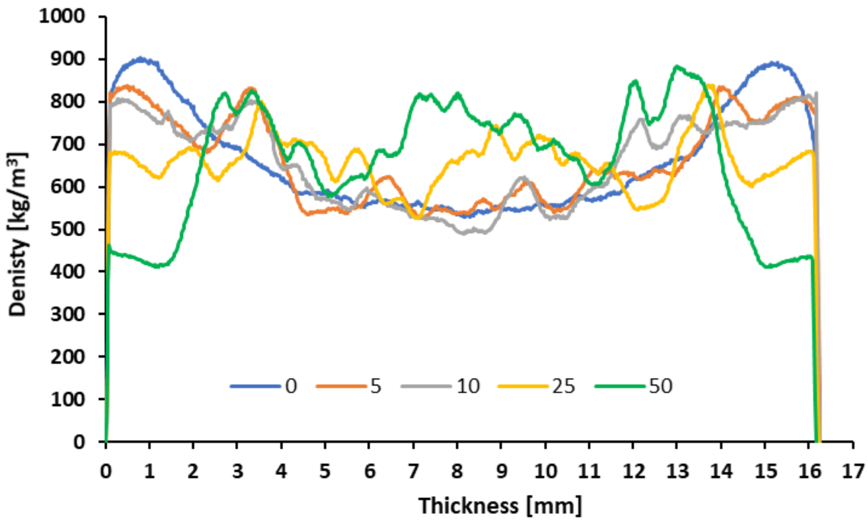

Figure 7. The density profiles of tested samples

CONCLUSIONS

According to the tests conducted and the analysis of the results obtained, it can be deduced:

- The modulus of elasticity and bending strength decreased as the content of artificial leather particles increased, but still met European standards when the content of artificial leather particles is less than 10%.
- Internal bond values decreased significantly compared to the reference board and steadily decreased with the increase in the content of artificial leather particles in the board.
- Thickness swelling and water absorption decreased as the content of artificial leather particles increased.
- The screw withdrawal resistance for the 5 and 10% boards is comparable to the values for the 0% board.
- The best mechanical and physical properties were obtained for boards with 5 and 10% artificial leather content.

- As the artificial leather content increases, the density profile becomes more irregular and the higher density gradually shifts towards the core layer.

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Streszczenie: *Wpływ zawartości cząstek sztucznej skóry z recyklingu na właściwości płyt wiórowych.* Sztuczna skóra to warstwowy kompozyt tkaninowo-plastikowy, który swoim wyglądem przypomina skórę naturalną. Ze względu na szeroki wachlarz zalet sztuczna skóra jest powszechnie stosowana jako materiał obiciowy w renowacji i produkcji mebli czy nawet tapicerki samochodowej. Celem badań było zagospodarowanie odpadów skór tapicerskich poprzez dodanie do płyt wiórowych uprzednio rozdrobnionych kawałków sztucznej skóry o różnej zawartości (5, 10, 25 i 50% wag.). Zakończono badania wybranych właściwości mechanicznych (wytrzymałość na zginanie i moduł sprężystości oraz odporność na wyciąganie wkrętów) oraz fizycznych (profil gęstości, pęcznienie grubości po zanurzeniu w wodzie). Można stwierdzić, że w zależności od dalszego wykorzystania płyty istnieje możliwość wykorzystania odzyskanych kawałków skaju jako rozsądnego dodatku do włókien drzewnych w produkcji płyt wiórowych.

Słowa kluczowe: recykling, płyta wiórowa, sztuczna skóra, meble tapicerowane, gospodarka obiegu zamkniętego

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