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Waste Banana Peel Flour as a Filler in Plywood Binder

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Abstract: *Waste banana peel flour as a filler in plywood binder*. Waste banana peel flour has gained attention as a potential filler in plywood binders due to its abundance, low cost, and positive environmental impact. Banana peels, which are typically discarded as waste, can be processed into flour and incorporated into plywood binders, offering several advantages. Firstly, banana peel flour acts as a natural filler, increasing the volume and reducing the amount of more expensive fillers required in plywood production. This can lead to cost savings without compromising the overall quality of the plywood. Secondly, banana peels contain a significant amount of cellulose and starch, which contributes to the strength and stability of the binder. The cellulose fibers present in the peel flour improve the adhesive's mechanical properties, enhancing the plywood's resistance to warping, bending, and cracking. Furthermore, banana peels are rich in phenolic compounds, such as tannins, which possess adhesive properties. These compounds can enhance the bonding strength between the veneer layers in plywood, resulting in improved overall structural integrity. Using waste banana peel flour as a filler in plywood binders also presents environmental benefits. By repurposing banana peels, which would otherwise end up in landfills, it reduces waste and promotes sustainability. The study aimed to investigate the influence of various contributions of banana peel flour in bonding mass on the properties of plywood produced with such an investigated binder. The following plywood features have been tested: modulus of rupture and modulus of elasticity, bonding quality (shear strength and in-wood damage) and density profile. The achieved results have been referred to as the control plywood produced with regular, industrially composed bonding mass. The structure of banana peel has been characterized as well. The results have shown that waste banana peel flour can be a valuable replacement of commercially applied filler in plywood technology.

Keywords: plywood, binder, glue, filler, banana, peel, waste

INTRODUCTION

The technology used in plywood manufacturing has remained relatively unchanged for over a century. However, research is being carried out all the time to improve its quality. The main changes in plywood improvement are due to the use of more modern equipment or new adhesives (Starecki 1992). On a daily basis, the furniture industry uses adhesives with the addition of various fillers for plywood production. They improve the physical-mechanical, technological and operational properties. Fillers are divided into organic and inorganic ones. The first group includes such materials as wood flour, starch, wheat flour, soybean meal or lignin. Inorganic substances include kaolin, chalk, asbestos, gypsum and even finely ground glass. Organic fillers swell in water well, actively absorb moisture, increase the viscosity of the adhesive and reduce glue dripping from the applied veneers. Banana peels contain a substantial amount of starch, approximately 18.5% (Astuiti and Erprihana 2014), so they can be a potentially good filler in a plywood manufacturing.

Plywood production is a process in which a huge amount of waste is generated. It can be minimized by conducting consistent control of the production process. According to literature sources, this efficiency varies from 35 to 60% (Kurowska 2016). One of the most important ways to protect the environment is to reduce waste. That's why researchers focus on making the most of it, often proving that it provides many additional advantages. For example, Kawalerczyk et al. (2020) write in their study about the positive effect of bark additives on adhesive viscosity. Kilani et al. (2022) observed that banana and orange peels have great potential for concrete reinforcement. In another article, we learn that the use of fillers such as hemp flour, coconut flour or rice flour can significantly reduce the gel time of the glue mixture. Furthermore, using hemp flour as an adhesive filler reduces formaldehyde emissions (Kawalerczyk et al. 2019).

A banana peel consists of an outer protective layer as well as an inner - fleshy part. Depending on the species and stages of ripeness, banana peels can vary in color and size, while the chemical composition of the peel remains similar in each case. Emaga et al. (2011) in their study showed that ripening of the fruit was associated with an increase in soluble sugars and a simultaneous decrease in starch content. For example, green banana peels contain significantly less starch (about 15%) than plantain banana peels, while ripe banana peels contain up to 30% free sugars. Banana peels have a high fiber content of 20% to 30% and are rich in carbohydrates, proteins, dietary fiber, as well as mono and disaccharides (in terms of chemical composition, the peel of the common banana (*Musa sapientum*) contains a significant amount of carbohydrates, as much as 59% (Anhwange et al. 2009).

Banana peels, with a biodegradation period of up to two years, typically end up in municipal landfills, adding to environmental challenges. They account for 3.5 million tons of waste per year (Mishra et al. 2023). An alternative method of handling banana waste involves repurposing it as a filler in plywood technology, presenting a more eco-friendly disposal option.

The study aims to present an alternative way to reduce waste and to see how glue mixture with banana peel flour as a filler will affect the quality of plywood.

MATERIALS AND METHODS

The raw materials listed below were used to make the tested material:

- Ripe banana peels divided into three groups: banana outer skin, banana core skin and mix (outer and core skin together) as a tested filler
- Rye starch as a filler in the reference sample
- Pine (*Pinus sylvestris* L.) veneers, 3.2 mm thick, 5.5% moisture content (M.C.)
- Urea-formaldehyde (UF) resin, commercial, Silekol S-123 (Silekol Sp. z o. o., Kędzierzyn, Koźle, Poland), about 66% dry content, molar ratio of about 0.9
- Hardener - a water solution containing 40% of ammonium nitrate dry matter
- Demineralized water (to tune the viscosity of bonding mass)

After collecting a large enough number of ripe banana peels, they were separated into three groups. The first group included the outer skin of the banana itself, without the pulp. The second group included the peel's inner surface pulp, which was separated from the peel with a spoon. The third group had a mix of the entire peel. The whole was dried in a dryer (Thermolyne, OV47415 Oven Series 9000). The dried banana peels and pulp had to be ground to a fine dust in a coffee grinder. The dust was sifted through a sieve with a 0.1 mm mesh.

For each of the three groups, three-layer plywoods were made, differing in the parts by weight (pbw) of the substances used for the glue compound. A thin layer of glue mixture with a grammage of 180 g/m^2 was evenly applied to the veneers with a brush. The bonding mass components content (especially hardener to resin ratio) has been set to reach the curing time at 140°C of the reference bonding mass of about 86 s. The veneers were pressed together in a high-temperature hydraulic press *(*AKE, Mariannelund, Sweden*)*. The pressing temperature was 140°C and the unit pressing pressure was 1.5 MPa. Following the pressing phase, they underwent air-conditioning at 20°C and 65% humidity to achieve weight stabilization.

The following plywood features have been tested: modulus of rupture (bending strength; MOR) and modulus of elasticity (MOE), bonding quality (shear strength and in-wood damage), density profile and filler water absorption. Bending elasticity and strength were assessed using a computer-controlled universal testing machine (Research and Development Centre for Wood-Based Panels Sp. z o. o. Czarna Woda, Poland), adhering to the EN 310 (1993) standard, with a minimum of 10 samples tested for each variant. The tensile strength of each variant was evaluated on a minimum of 10 samples in accordance with the EN 205 (2016) standard, employing a standard testing machine. The maximum load (in Newtons) was applied relatively to the bond line area. Subsequently, following sample breakage, an analysis of each damaged zone was conducted to estimate the percentage of damage in the wood. The density profile of the samples was examined using a DA-X measuring instrument (Fagus-GreCon Greten GmbH and Co. KG Alfeld/Hannover, Germany). The measurement, conducted through direct scanning X-ray densitometry, involved a scanning speed of 0.5 mm/s across the panel thickness with a sampling step of 0.02 mm. The samples, with nominal dimensions of 50 mm × 50 mm, were utilized for this analysis. A minimum of three samples from each composite type were employed to assess the density profile. Then, the representative profile per every tested variant has been selected for further evaluation and presentation in plots. Water filler absorption underwent testing following the soaking parameters. Filter paper containers were employed in the experiment. Each container received approximately 1-2 grams of tested filler (rye flour or a selected fraction of banana peel flour). Two repetitions were conducted for each variant. Subsequently, each sample underwent a 10-minute soaking period in demineralized water at a temperature of approximately 20°C ±1°C, followed by a 10-minute free-draining phase. The weight of the samples was then checked.

Depending on the amount of flour as a filler, the plywood was created in ten variants:

1. Plywood with 5 pbw banana outer skin peel flour as a filler (BO5)
2. Plywood with 10 pbw banana outer skin peel flour as a filler (BO10)
3. Plywood with 20 pbw banana outer skin peel flour as a filler (BO20)
4. Plywood with 5 pbw banana core skin peel flour as a filler (BC5)
5. Plywood with 10 pbw banana core skin peel flour as a filler (BC10)
6. Plywood with 20 pbw banana core skin peel flour as a filler (BC20)
7. Plywood with 5 pbw banana mix peel flour as a filler (BMIX5)
8. Plywood with 10 pbw banana mix peel flour as a filler (BMIX10)
9. Plywood with 20 pbw banana mix peel flour as a filler (BMIX10)
10. Plywood with 10 pbw rye flour as a filler (reference; REF)

The achieved results have been referred to as the control plywood produced with regular, industrially composed bonding mass with a 10 parts by weight of rye flour as a filler.

RESULTS AND DISCUSSION

Determination of Modulus of Elasticity in Bending (MOE) and of Bending Strength (MOR)

The results of the measurement of the modulus of elasticity in the bending (MOE) of plywood with the use of banana peel as a filler are presented in figure 1. The highest result was achieved by the sample with banana core skin peel filler (BC5) 9288 N/mm^2. A slightly lower result but higher than the reference sample was achieved by the sample with banana mix filler (BMIX10) 9082 N/mm^2. The lowest result came out for the sample (BMIX20) and was 7187 N/mm^2. Statistically significant differences in mean values for elastic modulus were noted only for BMIX20 relative to the other results. In the case of Daniłowska and Kowaluk (2020) study about the use of coffee bean post-extraction residues as a filler in plywood technology, the highest MOE value was 12557 N/mm^2. Similar to our study, their research found that the samples with the highest filler content had the lowest value.

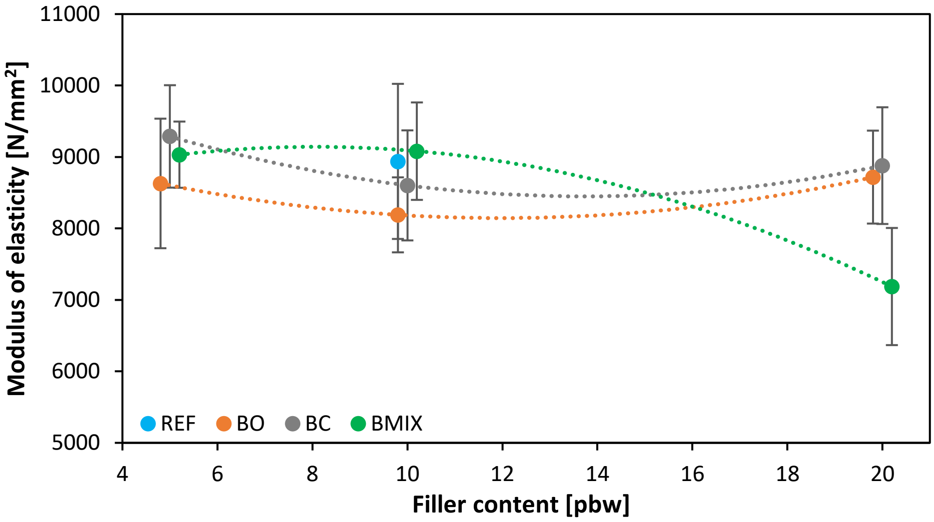

Figure 1. Modulus of elasticity of tested samples

The results of the measurement of the bending strength (MOR) of plywoods bonded with the use of banana peel and rye flour as a filler are presented in figure 2. The reference sample had the highest result in bending strength and it was 82.6 N/mm^2. 45.8 N/mm^2 was the lowest result and it was obtained by the sample with the highest banana mix filler content BMIX20. Samples with 10 parts by weight of filler have the highest average bending strength.

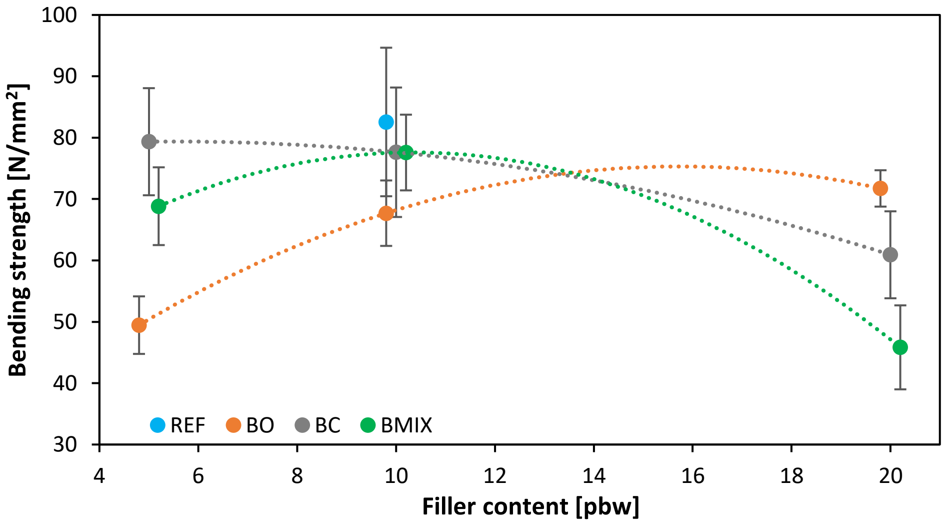

Figure 2. Modulus of rupture of tested samples

Reh et al. (2021) studied the effect of adding birch bark as a filler in plywood production. They made plywood with 10, 15 and 20 parts by weight per 100 parts by weight of liquid UF resin. In their study, they also noted that the sample with an intermediate amount of filler

(15 pbw) has the highest bending strength score, and that the shear strength decreases as the filler content increases.

Shear strength testing

The graph shown in figure 3 displays the influence of banana peel flour on the shear strength of the boards produced. As it is evident from the graph, all samples, when referring to 10 pbw with banana peel as a filler, have a higher shear strength than the reference sample. The highest shear strength is 2.45 N/mm^2 and this shows the sample BC5 with banana core skin as a filler. The BMIX20 sample revealed a shear strength of 1.02 N/mm^2, representing the lowest result in the shear strength test. Only in some of the BMIX10 and REF samples was damage observed in the wood. All other plywood samples achieved values in accordance with EN 314-2 (1993). In the case of samples with banana core skin and mix as a filler, a relationship is apparent where shear strength with the amount of filler increases and then decreases again. In contrast, it is completely different for banana core skin as a filler where shear strength with the amount of filler decreases and then increases again.

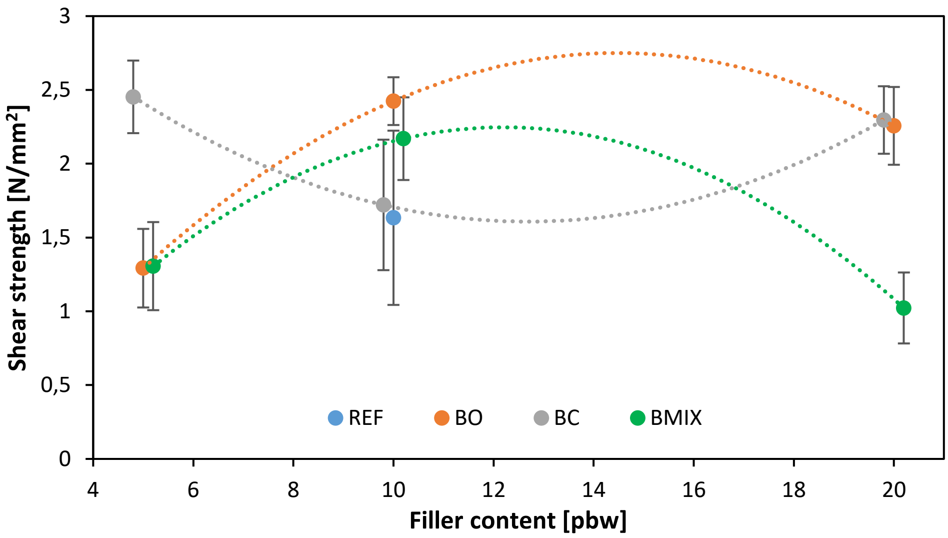

Figure 3. Shear strength of tested samples with various contents of banana peel flour as a filler

Density profile

The results of the density profile measurement are given in figures 4a-4d. The lowest value in the inner layer was obtained by the sample with the lowest amount of filler BMIX5 while the highest value in this layer was obtained by sample BO10. As for the outer layers, the highest density was obtained by the BO20 sample, while the lowest BO5. As can be seen, the graphs of most samples are similar to each other and shaped like a "U" letter. The most different results were obtained by samples BC10 as is evident in figure 4b. Also, as has been presented in figure 4b, the increasing filler content causes a reduction in veneer penetration by the binder, which is indicated by more narrow peaks of the bonding lines.

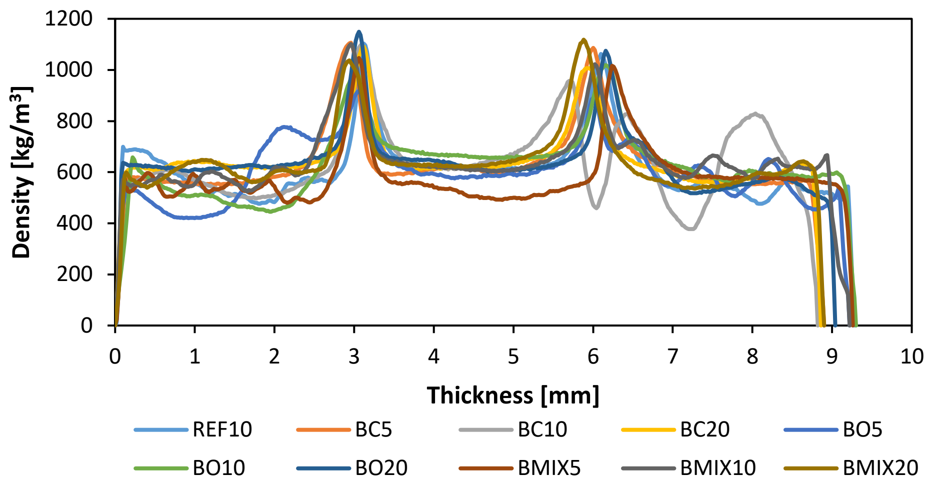

Figure 4a. The density profiles of tested samples

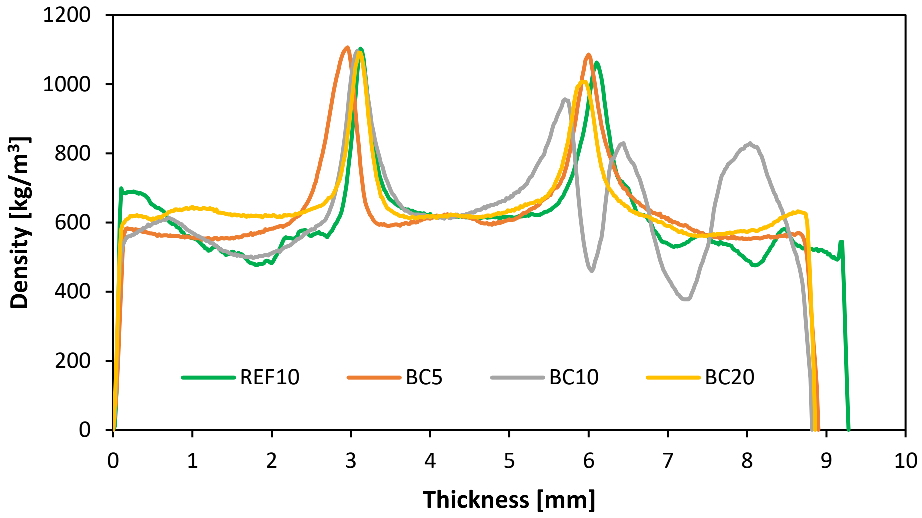

Figure 4b. The density profiles of tested samples with banana core skin flour as a filler

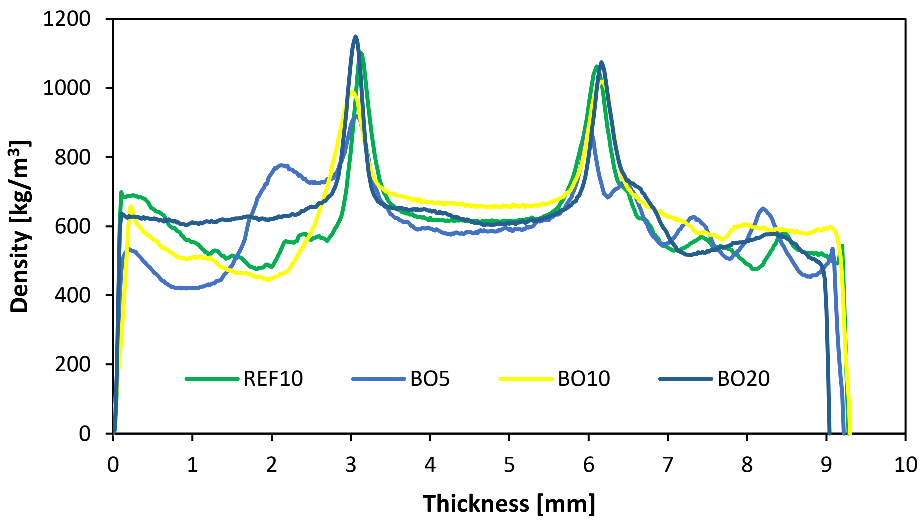

Figure 4c. The density profiles of tested samples with banana outer skin flour as a filler

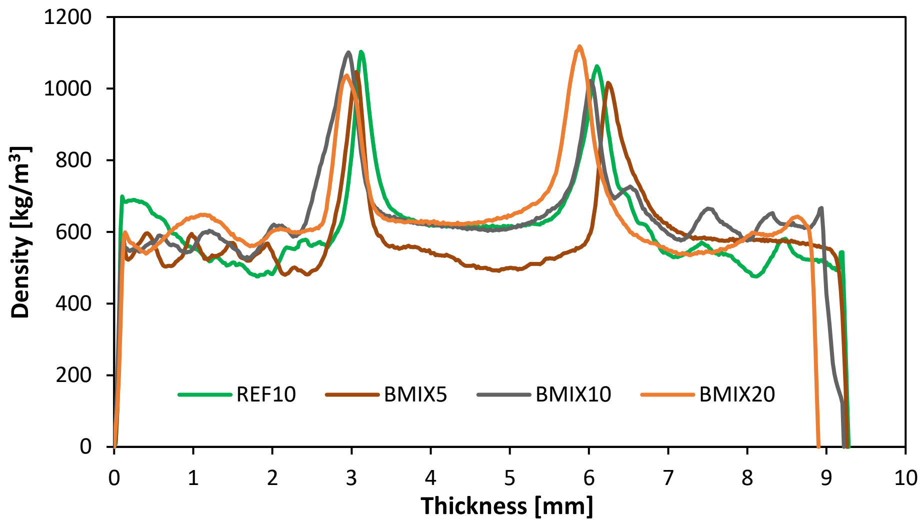

Figure 4d. The density profiles of samples with banana mix flour as a filler

Filler Water Absorption

Figure 5 presents the results of flour water absorption. As we can see from the graph, the absorption came out significantly higher for the samples tested comparing to the reference sample (224%). The sample with banana outer skin flour as filler has the highest water absorbency, as much as 531%. This is almost twice the result of the reference sample. The sample with banana core skin has a slightly lower absorbency because it is 330%. In contrast, the sample with banana mix peel flour has an intermediate result (412%), which would agree that it is a mix of outer and core skin. Such a high score may be due to the structure of the banana peel (Vonnie et al. 2023). The high water absorption by banana peel filler can contribute to the properties of the binder in plywood. Thus, optimization steps should be made to reduce the amount of banana peel filler without the loss of the proper level of remaining properties of produced plywood.

Dasiewicz and Wronka (2023) in their search with the addition of chestnut peel powder as a filler in plywood production achieved a result close to the reference sample (228%).

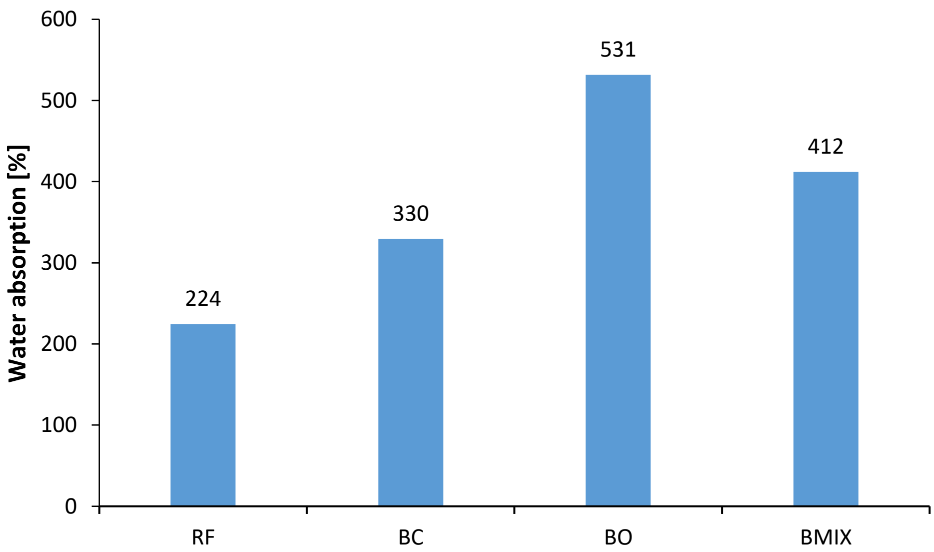

Figure 5. Water absorption of banana peel flour

CONCLUSIONS

On the basis of conducted investigations on the influence of type and content of banana peel flour as a filler in plywood bonding mass, and result analysis, the following conclusions and remarks can be drawn:

1. From the arithmetic mean, it can be seen that as the filler content increases, the modulus of elasticity of the plywood with banana peel flour decreases.
2. Despite the fact that the bending strengths of all tested samples were lower than that of the reference sample, each of them still complied with European standards.
3. All samples with banana peel as a filler, when referred to as 10 pbw, have a higher shear strength than the reference sample.
4. Most samples exhibited a density profile that was symmetrical concerning the two outer layers, and the vertical density profiles took on a "U" shape. The density profile confirms, that with the increasing filler amount, the impregnation of veneers by binder decreases.
5. The water absorption of banana peel filler samples is significantly higher than the reference sample. Thus, optimization steps are worth undertaking to reduce the amount of banana peel filler without loss of the proper level of remaining properties of produced plywood.

The study's outcomes demonstrate the potential of waste banana peel flour as a valuable alternative to conventional fillers used in plywood technology.

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Streszczenie: *Odpadowa mączka ze skórek bananów jako wypełniacz w spoiwie do sklejki*. Odpadowa mączka ze skórek bananowych zyskała uwagę jako potencjalny wypełniacz spoiw sklejkowych ze względu na swoje właściwości takie jak niski koszt czy pozytywny wpływ na środowisko. Skórki bananów, które zazwyczaj są traktowane jako odpad, można przetworzyć na mączkę i dodać do spoiw sklejkowych, co niesie ze sobą wiele zalet. Po pierwsze, mączka ze skórek bananowych działa jak naturalny wypełniacz, zwiększając objętość i redukując ilość droższych wypełniaczy potrzebnych przy produkcji sklejki. Może to prowadzić do oszczędności kosztów bez uszczerbku dla jakości sklejki. Po drugie, skórki bananów zawierają znaczną ilość celulozy i skrobi, które przyczyniają się do wytrzymałości i stabilności spoiwa. Włókna celulozowe obecne w mączce poprawiają właściwości mechaniczne kleju oraz zwiększają odporność sklejki na wypaczenia, zginanie i pękanie. Ponadto, skórki bananów bogate są w związki fenolowe, takie jak garbniki. Związki te mogą zwiększać siłę wiązania pomiędzy warstwami forniru w sklejce, co skutkuje wzmocnieniem jej struktury. Stosowanie odpadowej mączki ze skórek bananowych jako wypełniacza w spoiwach ze sklejki zapewnia również korzyści dla środowiska. Poprzez ponowne wykorzystanie skórek bananów, zmniejszona zostaje ilość odpadów. Celem pracy było zbadanie wpływu udziału mączki ze skórek bananowych w masie klejowej na jakość sklejki wytworzonej z taką masą. Zbadano następujące cechy sklejki: wytrzymałość na zginanie, moduł sprężystości, jakość sklejenia (wytrzymałość na ścinanie) i profil gęstości. Uzyskane wyniki porównano ze sklejką kontrolną wytworzoną z konwencjonalnej masy wiążącej. Opisano także strukturę skórki od banana. Wyniki wykazały, że odpadowa mączka ze skórek bananowych może stanowić cenny zamiennik komercyjnie stosowanych wypełniaczy w technologii sklejki.

Słowa kluczowe: sklejka, spoiwo, klej, wypełniacz, banan, skórka, odpad

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