

Influence of the use of chestnut starch as a binder filler in plywood technology

JULIA DASIEWICZ¹, ANITA WRONKA²

¹ Faculty of Wood Technology, Warsaw University of Life Sciences-SGGW, Warsaw, Poland

² Department of Technology and Entrepreneurship in Wood Industry, Institute of Wood Sciences and Furniture, Warsaw University of Life Sciences – SGGW

Abstract: *Influence of the use of chestnut starch as a binder filler in plywood technology.* Fillers play a crucial role in the production of plywood glues, providing enhanced performance and stability to the end product. Plywood, being a composite material, requires fillers to improve its mechanical properties, adhesion, and overall quality. One common filler used in plywood glues is calcium carbonate. It acts as a bulking agent, increasing the volume and density of the adhesive mixture while reducing production costs. Calcium carbonate also enhances the glue's viscosity, ensuring proper bonding and uniform application during the plywood manufacturing process. Another widely used filler is rye or wheat flour, which consists of finely ground grains. The flour not only improves the adhesive's viscosity but also contributes to the overall strength and stability of the plywood. It helps to prevent warping and enhances dimensional stability, making the final product more durable. Additionally, other fillers like talc or clay minerals may be incorporated into the glues to improve their adhesive properties and increase moisture resistance. Chestnut starch is a type of vegetable flour made by grinding edible chestnuts into a powder. It has a different texture and properties than traditional wheat or rye flour. When used as a binder filler in plywood technology, it can be biodegradable and environment-friendly. In the study, there were produced five types of plywood with 0, 1, 5, 10, and 20 parts by weight chestnut flour and one reference. All samples were produced in laboratory conditions and the selected mechanical and physical properties of the produced boards were studied. The mechanical properties of the boards increased with the addition of chestnut flour. In some tests, the results even met the highest requirements of European standards for plywood. According to this finding, a well-chosen addition of chestnut flour could be positively considered in plywood production.

Keywords: plywood, chestnut, flour, layered composite, filler

INTRODUCTION

Researchers are constantly looking for new alternatives to rye flour in order to expand our knowledge of fillers. As a part of plywood production technology, flour plays an important role. When the viscosity of the glue is not too low, then it is possible to obtain a good-quality joint. This is because it is responsible for ensuring that the glue has the correct viscosity. The gelling times and quality of the joints may vary depending on the type of flour used. The quality of the joints may also differ depending on the porosity and pH of the filler being used (Kawalerczyk et al. 2019) and also on the type and quality of veneers used (Jivkov et al. 2012).

In addition to viscosity control, fillers can also have other properties that can improve the quality of plywood, such as the ability to absorb formaldehyde, which in most cases

accompanies wood-based products. Tests conducted to date confirm that hemp flour, for example, has this ability (Kawalerczyk et al. 2020), but also pine bark powder (Walkiewicz et al. 2022) and birch bark powder (Bekhta et al. 2021). With acidic fillers, the curing time of the adhesive is reduced (Ježo et al. 2023). Residues used as a filler also include coffee beans (Daniłowska and Kowaluk 2020), soy flour (Hand et al. 2018), walnut shell (Pirayesh et al. 2012) palm kernel meal (Ong et al. 2018), waste rubber powder (Ong et al. 2015), lignocellulosic waste fibers (Bekhta et al. 2019) and starch with citric acid (Kusumah et al. 2020).

Plywood is a very popular product due to its strength properties, which is why it is used in construction - for walls, floors, roofs, load-bearing beams and other structural elements (Persson and Hedlund 2021), in the furniture industry - for making cabinets, tables, chairs and beds, and therefore can also be used to finish furniture surfaces or as a basic construction layer (Hasan and Ramić 2021). Due to its lightweight and strength, plywood is a popular material in the transport industry. It is used in the manufacture of cargo boxes, pallets, containers and floors for trucks, aircraft and ships (Fitzpatrick 2023).

Gluten-free products are becoming increasingly popular (Carreira et al. 2015). People with intolerances have to look for alternatives to wheat flour, which raises the curiosity of raw material researchers, not only from the food industry. Chestnut flour, which has so far been used as a filler for vinyl ester composites (Kartal et al. 2020), could be a substitute. Due to its consistency, which is similar to wheat flour, there is the potential to use chestnut flour as a filler in plywood technology. The aim of this research was to investigate the influence of the addition of chestnut flour as a filler to plywood bonding mass on selected mechanical and physical properties of produced plywood.

MATERIALS AND METHODS

Materials used to make the tested material:

- Birch (*Betula L.*) veneers 1.8 mm thick, about 5.5% moisture content (MC)
- Urea-formaldehyde (UF) resin Silekol S-123, 65% solid content (EN 827 2005) (*Silekol Sp. z o. o., Kędzierzyn-Koźle, Poland*)
- Hardener - 2% of dry matter of ammonium nitrate water solution
- Chestnut starch as a filler (*Producer: Bio Planet S.A. Wilkowa Wieś 7 05-084 Leszno, Poland*)
- Rye starch as a filler in the reference sample (*Producer: BioLife Sp.z.o.o. ul. Miodowa 17, 17-100 Bielsk Podlaski, Poland*)
- Demineralized water

A three-layer plywood was created using chestnut starch as a filler. The amount of chestnut starch-based filler was set differently for each variant, depending on a predetermined content. The glue mixture was evenly manually applied in the amount of 180 g/m² to the veneers with a brush. After the veneers were joined together in a suitable manner the samples were pressed in a high-temperature press (AKE, Mariannelund, Sweden; pressing temperature 140°C; unit pressing pressure 1 MPa) for 7 minutes. After pressing, they were air-conditioned at 20°C and 65% humidity for weight stabilization.

Depending on the amount of starch as a filler, the plywood was created in six variants:

1. Plywood with 0 part by weight (pbw) of added filler (hereafter called C0)
2. Plywood with 1 pbw chestnut starch as a filler (hereafter called C1)
3. Plywood with 5 pbw chestnut starch as a filler (hereafter called C5)
4. Plywood with 10 pbw chestnut starch as a filler (hereafter called C10)
5. Plywood with 20 pbw chestnut starch as a filler (hereafter called C20)
6. Plywood with 10 pbw rye flour (reference; hereafter called REF)

The exemplary bonding mass for 10 pbw was as follows: 100 pbw of resin, 10 pbw of filler, 5 pbw of hardener water solution and 10 pbw of demineralized water. The only filler type and content have been changed in produced samples.

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

The elasticity and strength in bending were carried out on a computer-controlled universal testing machine (Research and Development Centre for Wood-Based Panels Sp. Z o.o. Czarna Woda, Poland) following an EN 310 1993 standard on at least 10 samples in each variant.

Shear strength testing and in-wood damage evaluation

Tensile strength was tested on at least 10 samples per variant according to EN 205 2016 using a standard testing machine. Tensile strength was applied as the maximum load [N] relative to the bond line area. In addition, after the samples were broken, each zone damaged zone was analyzed to estimate the area of damage in the wood (%).

Density profile

The density profile of samples was analyzed using a DA-X measuring instrument (Fagus-GreCon Greten GmbH and Co. KG, Alfeld/Hannover, Germany). The measurement based on direct scanning X-ray densitometry was carried out with a speed of 0.5 mm/s across the panel thickness with a sampling step of 0.02 mm. Samples were cut into 50 mm × 50 mm nominal dimensions. Three samples of each type of composite were used to study the density profile.

Filler Water Absorption

For the test, 4 filter paper containers were used. Approximately 1-2 g of rye flour and chestnut flour were poured into each container. Two repetitions were carried out for each variant. Each sample was soaked for 10 minutes in demineralized water at a temperature of approximately 20°C ±1°C, followed by 10 minutes of free draining - after which the weight of the samples was checked.

Statistical Analysis

The statistical significance of the average values between factors as well as levels has been estimated by analysis of variance (ANOVA) and t-tests calculations ($\alpha = 0.05$), Duncan test, where applicable, with use of IBM SPSS statistic base (IBM, SPSS 20, Armonk, NY, USA).

RESULTS AND DISCUSSION

Determination of Modulus of Elasticity in Bending and of Bending Strength

The results of the measurement of the modulus of elasticity in the bending of plywood with the use of chestnut starch as a filler are visualized in Figure 1. As can be clearly seen from the graph, as the chestnut filler increases, the modulus of elasticity increases. The highest result came out for the highest chestnut starch content (C20) 17753 N/mm² and this is also a higher result than for the reference sample (REF) 14734 N/mm². The lowest result came out for the sample with the lowest addition of chestnut filler (C1) 12997 N/mm² and curiously this is lower than the sample without any filler added (C0) 14222 N/mm². The only statistically significant difference in MOE mean value has been found for C20 plywood when referring to the remaining tested samples.

Similar results came out in a study on the effect of the addition of post-treated bark biomass to the binder on the properties of the produced plywood (Ježo et al. 2023). A significant increase in MOE was observed with increasing filler content. However, the maximum MOE was recorded for around 10% filler content. Further increases in filler content reduce the MOE. The MOE results were also found to be highly reproducible.

In contrast, in the research of Kawalerczyk et al. (2019) on the subject of flour fillers with urea-formaldehyde resin in plywood, the modulus of elasticity came out different depending on the type of filler used. The best results were obtained for plywood glued with pumpkin flour and rye flour. In contrast, the addition of coconut flour had a negative effect and caused a decrease in MOE properties.

Interesting results and research were presented by Dasiewicz and Kowaluk (2022) on the manufacture and layering of biopolymer composite bonded with a cellulose-based binder. The best MOE results were shown by sample B2 made of beech wood with a longer pressing time and had better results than reference sample B0. Sample B1 of beech wood pressed in a shorter time showed the worst results. Ash plywood samples have the opposite results to beech plywood samples. Sample A0 has the best results than B1 and B2. Thus, a binder based on regenerated cellulose was found to have a beneficial effect on MOE properties.

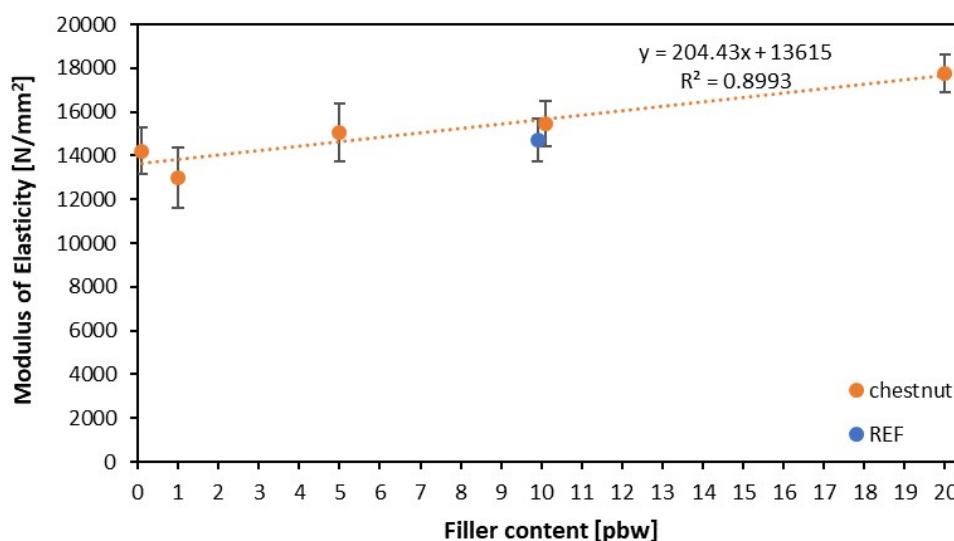


Figure 1. Modulus of Elasticity of tested samples with various content of chestnut flour as a filler

The results of the measurement of the bending strength of plywood bonded with the use of chestnut starch as a filler are visualized in Figure 2. The sample with the highest chestnut filler content (C20) shows the highest result of 154 N/mm² and this is higher than the reference sample (REF) of 147 N/mm². The lowest result came out for the sample with the lowest addition of chestnut filler (C1) 71.5 N/mm² and, as with the MOE test, the sample without filler (REF) has a higher score of 109 N/mm² than sample C1. The only statistically significant difference in MOR mean value has been found for C1 plywood when referring to the remaining tested samples.

In a study on the use of bark particles of different sizes as a urea-formaldehyde resin filler in plywood (Mirski et al. 2020) it was found that bark powder with a size fraction of 0.315 mm could be used instead of rye flour to produce plywood giving good mechanical properties. The results came out similar compared to the control samples but a bit better. In contrast, the values obtained for every other variant were significantly lower than the reference sample. The 0.315 mm fraction bark filler adhesive had a similar viscosity to the reference adhesive. The good rheological properties allowed even application and resulted in very good strength values.

In contrast, the research of Wronka et al. (2020) focused on the properties of hardboards glued together with potato starch. The modulus of rupture increases with increasing starch. The result for the sample with the highest amount of added starch, variant 20, was approximately 138% higher compared to the reference panel. Thus, it was concluded that starch can be used as a binder in the production of wet-formed fiberboard.

Interesting results were shown in a study on the properties of polypropylene/poplar flour composites with the addition of microcrystalline cellulose and starch powder (Asgari et al. 2020). It was observed, that the addition and higher amount of microcrystalline cellulose (MCC) and starch powder (SP) caused an increase in MOR. The sample that had the highest weight content of MCC and SP had the highest MOR.

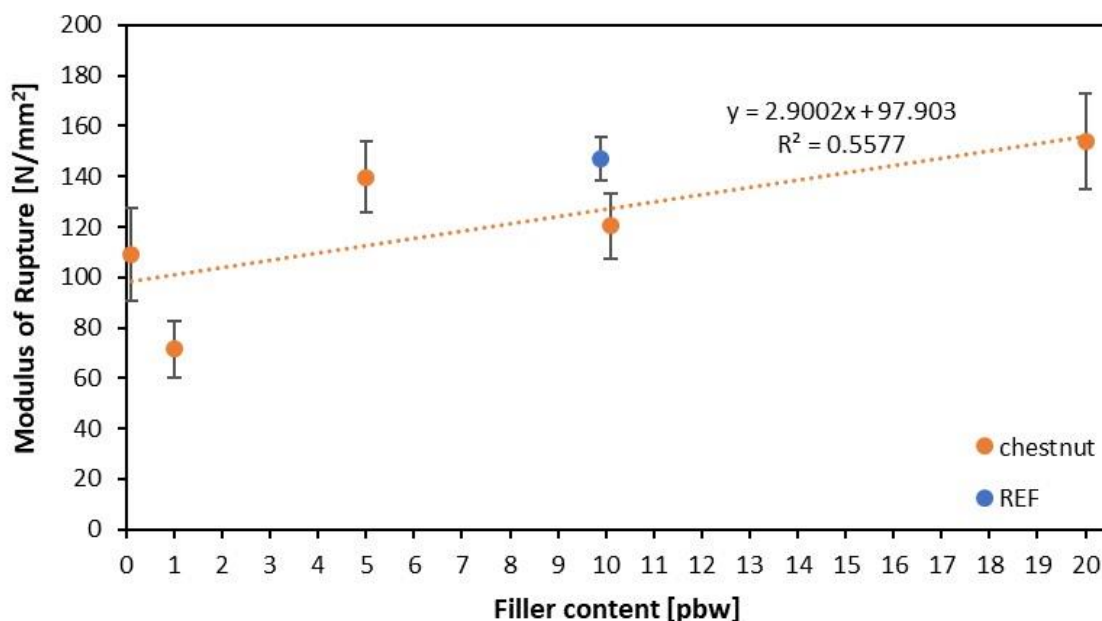


Figure 2. Modulus of Rupture of tested samples with various content of chestnut flour as a filler

Shear strength testing

The shear strength results are shown in Figure 3. As seen in the graph, all samples tested show similar shear strengths. The highest strength of 2.08 N/mm² is shown by the sample with 5% chestnut flour as filler. This is a higher strength than the reference sample of 1.83 N/mm² and the same strength was achieved by the sample with 10% added chestnut starch. The lowest shear strength is 1.67 N/mm² and this shows the sample without the addition of any filler. All samples tested showed a 0% failure rate in the wood structure. Thus, it can be concluded that the appropriate addition of chestnut flour as a filler can increase the shear strength. No statistically significant differences between the mean values of the tested samples have been found for shear strength.

Fukui et al. (2020) used fly ash from the combustion of woody biomass in their research as a filler in the production of plywood. The shear strength is almost constant at 0.95 MPa regardless of the type and diameter of the filler used. It was found that it is difficult to evaluate differences in adhesion due to the type of filler used on the basis of shear strength. In this case, adhesion is tested, among other things, by the wood damage factor. The red pine veneer was not damaged, but the cedar veneer was damaged. Glue with original ash has a lower wood damage factor, that is, lower adhesion than glue with calcium carbonate powder as filler. Higher values of the wood damage factor are shown by glue with treated ash without the unburned carbon component. It has been found that ash from the combustion of woody biomass as a filler for plywood can provide higher adhesion than calcium carbonate.

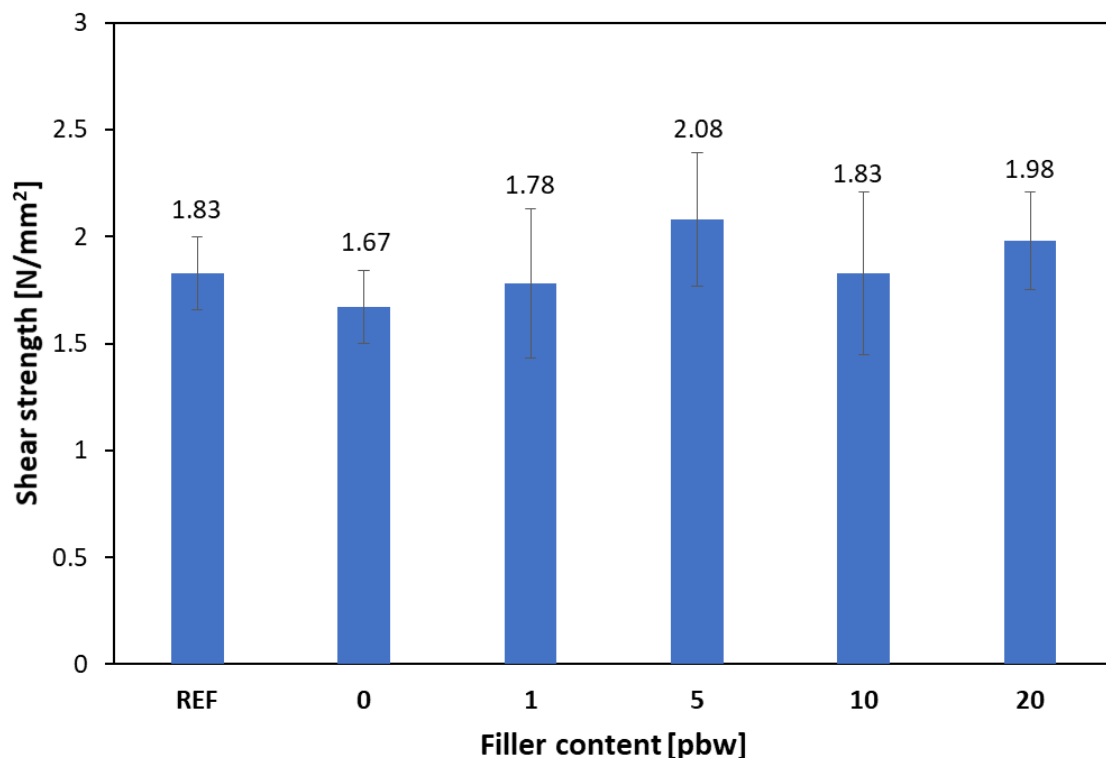


Figure 3. Shear strength of tested samples with various content of chestnut flour as a filler

Mirski et al. (2020) investigated the use of different fractions of ground birch bark as a filler for glue where the results for the 0.315 fraction were not statistically significant. The dry

values of the samples were 0.4194 and the values after soaking were 0.8914. The samples with a size fraction of 0.2 had the highest decrease, 26.3% dry and 23.6% after soaking. Regardless of the type of fraction, all plywood samples achieved values in accordance with the requirements of EN 314-2 (1993). Reference plywood bonded with birch bark-based filler glue showed a slight decrease in bond quality, but in tests with beech bark, the results came out the opposite (Réh et al. 2019).

The research of Bartoszek and Kowaluk (2022) on the effect of moisture on solid wood glued with modified starch compressive strength shows interesting results. The highest shear strength was 5.16 N/mm² for birch lamellae conditioned at 65% MC, and the lowest strength was for the sample conditioned at 100% MC and was 4.54 N/mm². It was noted that at the highest moisture content, the proportion of wood was lowest at 17%.

Density profile

The results of the density profile measurement have been displayed in Figure 4. As we can see from the graph, the density profile is symmetrical with respect to the two surface layers and the vertical density profiles showed a 'U' shape. The highest density in the inner layers is shown by the reference sample at 1224 kg/m³ where the inner layer is 677 kg/m³. A very similar result came out for the sample with the highest chestnut starch content (C20), where the density profile in the inner layers came out at 1190 kg/m³ and in the inner layers at 714 kg/m³. The lowest density in the outer layers came out for the sample without any filler added (C0) at 943 kg/m³, and the lowest density in the inner layers came out for the sample with the least chestnut starch added (C1) at 614 kg/m³.

Interesting results were shown in a study on the properties of green particleboard made from coconut fiber glued together with a potato starch-based binder (Owodunni et al. 2020). Graphs of all samples showed a flat density gradient. Density gradient native potato starch (NPS) showed a flatter density gradient than other particleboard samples. It was observed that the density gradually decreased towards its thickness until it reached the central area and was flatter in the core.

In the research of Neitzel et al. (2023) on medium-density fibreboard bonded with dialdehyde starch-based adhesive, the average density of the MDF panels ranged from 656 to 688 kg/m³. In the control panels bonded with MUF glue, the density showed a gradual increase at the edges and showed smaller differences in density between the edges and parts of the core compared to panels produced with DAS and eMDI-based adhesives.

In the research of Gumowska and Kowaluk (2023), the average density of all samples was 900 kg/m³. The density profiles for some HDF samples showed symmetry with respect to the centre of the board thickness. The average density of the PCL12 samples in the outer layers was a value of 1090 kg/m³ and the density in the core layer decreased by 24%. The most homogeneous density profile was recorded for the PLA20 samples, where the density decreased in the core layer by about 6%. A homogeneous density profile was mainly recorded for the PLA20 samples there, where the density decreased by approximately 6% in the core layer.

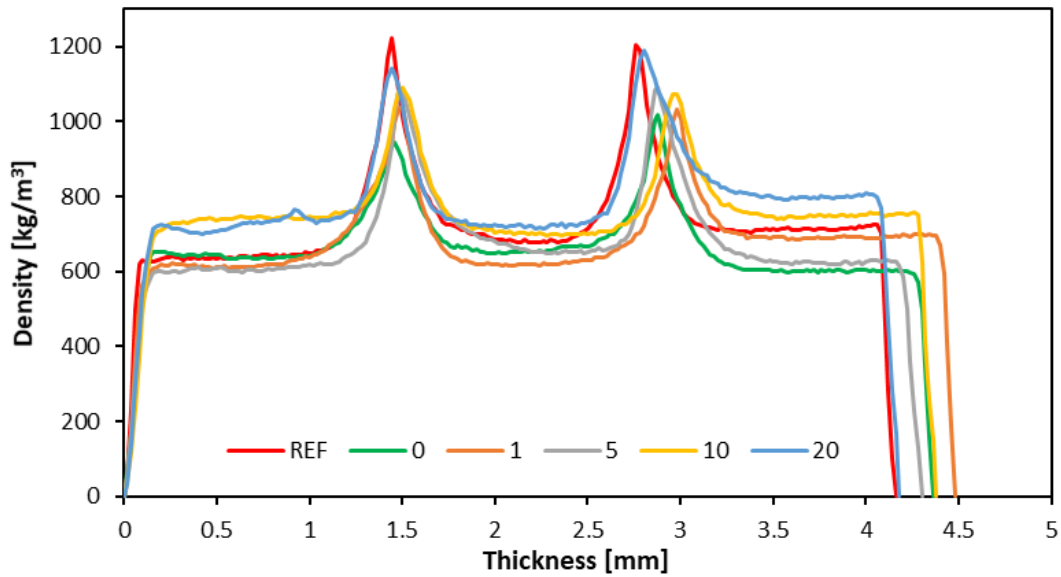


Figure 4. The density profiles of tested samples

Filler Water Absorption

The results of flour absorption are shown in Figure 5. As we can see from the graph, the absorption capacities of chestnut starch and rye starch are very similar. The absorption capacity of chestnut starch is 228% and that of rye starch is 224%. So, it can be concluded, that the differences in the water absorption of different flour fillers should not contribute to the properties of produced plywood samples.

The research of Wong et al. (2016) on fibre treatment to check oil absorption properties showed interesting results. Some treatments resulted in crude oil absorption by cotton burr and stem (CBS) and corn fibres showing an increase of 5 g/g, while motor oil absorption by burr, corn and soybean increased to 4-5 g/g. CBS and oak fibres showed low oil absorption capacity. CBS fibres 2.77 g/g (277%) and oak fibres are 1.68 g/g (168%).

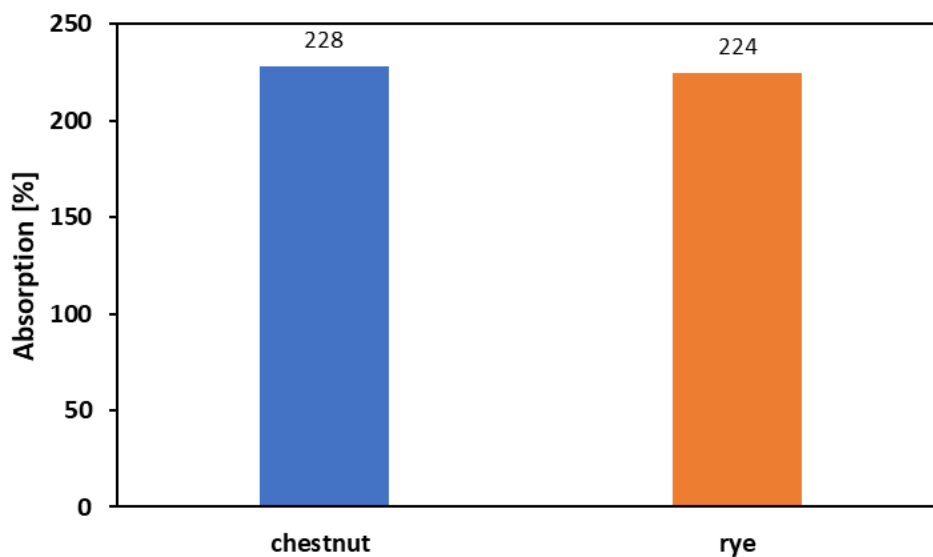


Figure 5. Water absorption of chestnut flour and rye flour

CONCLUSIONS

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

1. As the addition of chestnut filler increases, the modulus of rupture and modulus of elasticity gradually increase and even reach the values of the highest requirements of European standards for plywood.
2. A well-chosen amount of chestnut filler can give very good and also better shear properties than the reference sample. In this case, the C5 sample obtained the highest shear strength value.
3. The density profile showed symmetry with respect to the two outer layers and the vertical density profiles showed a "U" shape.
4. Differences in absorbability between chestnut flour and rye flour are minimal.

In conclusion, the chestnut starch-based filler can replace fillers used in plywood technology in appropriately selected quantities.

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Streszczenie: *Wpływ zastosowania skrobi kasztanowej jako wypełniacza masy klejowej w technologii sklejki.* Wypełniacze odgrywają kluczową rolę w produkcji klejów do sklejki, zapewniając lepszą wydajność i stabilność produktu końcowego. Sklejka, będąca materiałem kompozytowym, wymaga wypełniaczy w celu poprawy jej właściwości mechanicznych, przyczepności i ogólnej jakości. Jednym z powszechnie stosowanych wypełniaczy w klejach do sklejki jest węgiel wapnia. Działa on jako środek wypełniający, zwiększając objętość i gęstość mieszanki klejowej przy jednoczesnym obniżeniu kosztów produkcji. Węgiel wapnia zwiększa również lepkość kleju, zapewniając prawidłowe wiązanie i równomierne nakładanie podczas procesu produkcji sklejki. Innym powszechnie stosowanym wypełniaczem jest mąka żytnia lub pszenna, która składa się z drobno zmielonych ziaren. Mąka nie tylko poprawia lepkość kleju, ale także przyczynia się do ogólnej wytrzymałości i stabilności sklejki. Pomaga zapobiegać wypaczaniu i zwiększa stabilność wymiarową, dzięki czemu produkt końcowy jest bardziej trwały. Dodatkowo, do klejów mogą być dodawane inne wypełniacze, takie jak talk lub minerały ilaste, aby poprawić ich właściwości klejące i zwiększyć odporność na wilgoć. Skrobia kasztanowa to rodzaj mąki roślinnej wytwarzanej przez mielenie jadalnych kasztanów na proszek. Ma ona inną teksturę i właściwości niż tradycyjna mąka pszenna lub żytnia. Stosowana jako wypełniacz spoiwa w technologii sklejki, może być biodegradowalna i przyjazna dla środowiska. W badaniu wyprodukowano pięć rodzajów sklejki z 0, 1, 5, 10 i 20 częściami wagowymi mąki kasztanowej i jedną referencyjną. Wszystkie próbki wyprodukowano w warunkach laboratoryjnych i zbadano wybrane właściwości mechaniczne i fizyczne wyprodukowanych płyt. Właściwości mechaniczne płyt wzrosły wraz z dodatkiem mąki kasztanowej. W niektórych testach wyniki spełniały nawet najwyższe wymagania norm europejskich dla sklejki. Zgodnie z tymi wynikami, dobrze dobrany dodatek mąki kasztanowej może być pozytywnie brany pod uwagę w produkcji sklejki.

Słowa kluczowe: sklejka, kasztany, mąka, kompozyty warstwowe, wypełniacz

Corresponding author:

Anita Wronka

Nowoursynowska Str. 159

02-787 Warsaw, Poland

email: anita_wronka@sggw.edu.pl