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Selected features of medium density fiberboards produced with the use of plant binder

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Abstract: *Selected features of medium density fiberboards produced with the use of plant binder*. The aim of the research was to determine the possibility of producing dry-formed fibreboards with the use of various proportions of plant glue as a binding agent. The scope of work included the production of boards in laboratory conditions with 0%, 10%, 12%, 14%, and 20% mass fractions of plant glue and subjecting them to selected physical and mechanical tests. The results show, that the properties of the produced panels are strongly connected to the content of the plant binder (resination), and, by the proper tuning of resination, it is possible to produce dry-formed fibreboards (MDF type) with the use of plant glue that meets the requirements of proper standards.

Keywords: fibreboard, MDF, plant glue, binder, resination

INTRODUCTION

Due to the limited resources of crude oil (Iannuzzi 2011), and unstable access to these, amine resins, broadly applied in wood-based panels production, are one of the main topics to find a sufficient replacement. The progress in biochemistry provides the opportunity to develop the binder based on plant, renewable resources. This approach significantly contributes to a sustainable, green industry policy.

The culture of conspicuous consumption is developing the economy without raising awareness about social costs primarily ecological damages. According to Bayer (2003), the flow of ecosystem services is strongly affected by changes in the environment, we still did not estimate the distribution of ecological damages and their driving forces. The environmental costs of human activities over 1961–2000 in six major categories (climate change, stratospheric ozone depletion, agricultural intensification and expansion, deforestation, overfishing, and mangrove conversion have been estimated. Artificial needs generate demand for new products without increasing awareness about harmful health. Boards technology as a restorative uses synthetic resin: urea-formaldehyde (UF), melamine-formaldehyde (MF), melamine-urea-formaldehyde (MUF), and phenol-formaldehyde (PF). The kind of applied resin depends on the destinations of produced boards. HDF boards contain UF or MUF resin, which has a free formaldehyde compound. Formaldehyde is recognized as a harmful gas bringing irritates the eyes and nasal mucosa. The International Agency for Research on Cancer (Anonym 2006) evaluated formaldehyde and concluded, that there is sufficient evidence that formaldehyde causes nasopharyngeal cancer in humans (Böhm et al. 2012). These factors lead to a search for binder solutions, that will not be harmful to humans, will come from renewable resources, their disposal will be easy, and mechanical properties will still be at the required level.

Kowaluk and Wronka (2020) proved, that the gelatin and acetic acid bonding mass, allow for reaching about 70% of the shear strength of PVAc glue shear strength when bonding birch sawmill wood. Examples of natural, plant-based adhesive substitutes include starch-based adhesives. Those can be obtained from various plant materials such as corn, potato, rice, wheat, sago, and much more widely available throughout the world. The application of starch and their by-products as a binding agent in wood technology has been widely tested (Qiao et al. 2016, Watcharakitti et al. 2022, Jiang et al. 2018, Jiang et al. 2019, Ye et al. 2018). Amini et al. (2013 and 2018) present their research on how to evaluate the weight loss of experimental particleboard made from *Hevea brasiliensis* using modified starch as a binder after contact with soil. When applied citric acid-modified corn starch as a binder, it was possible to reduce the influence of water on the weight loss of particleboards. The results show, that the 2% replacement of modified starch with urea-formaldehyde resin for the production of particleboard showed a reduction in the degradation of the particleboards produced with the use of glutardialdehyde-modified corn starch as the binder.

Starch has also been used as a binder for example in the production of particleboards bonded with sour cassava starch (Monteiro et al. 2019), hardboard (Wronka et al. 2020), and in the production of solid wood bonded with modified starch (Bartoszuk and Kowaluk 2022). Akinyemi et al. (2019) investigated the production of formaldehyde-free particleboards using glutaraldehyde-modified cassava starch as a binder. The results show that the modified cassava starch binder caused radical differences in the case of all the completed tests of the panels. It has been concluded that the use of modified cassava starch as a binder in the industrial production of particleboards should be recognized as a way of the utilization of the wastes generated during cassava processing and from wood processing which are in abundant supply in sub-Sahara Africa.

Research around the world demonstrates the possibility of replacing industrial glues with plant-origin glues. These technologies are the future of the whole industry and funds should be allocated to their development.

The aim of this work was to investigate the selected mechanical and physical properties of the MDF panels produced with various shares of plant-based resin as a binder. In the scope of research, the production of fiberboards of various resination by plant binder in medium-density-fiberboards technology on a laboratory scale has been completed, as well as characterization of the main mechanical and physical properties of the produced panels has been made.

MATERIALS AND METHODS

Materials

The panels were produced in laboratory conditions from industrially produced MDF-dedicated fibers from 95% by weight of pine (*Pinus sylvestris* L.) and spruce (*Picea abies* (L.) H.Karst) wood of about 3% of moisture content (MC).

The binder used in the research was plant-based resin, of 50% dry matter content, and a viscosity of about 530 mPa s. Due to ongoing work on the development of the mentioned binder, the producer did not provide the exact content and raw materials of the binder, however, describes it as consisting of recycled by-products of animal food production, cosmetics, and cellulose industry.

To produce the reference panels, an industrial, melamine-urea-formaldehyde (MUF) resin of 9% (by weight) of melamine content has been used. The curing time of the resin mixed with ammonium nitrate hardener in the ratio of 100:4 (by weight) at 100 °C was 82 s.

No hydrophobic agent has been used in panel production.

Production of the panels

A nominally 3 mm-thick fiberboard, with a nominal density of 740 kg/m^3 and resination by plant glue of 10%, 12%, 14%, and 20% by weight (hereinafter called variant 10, 12, 14, and 20). The resination of reference panels (hereinafter called industrial glue) was 12%. The binders were sprayed by air gun on the fibers mixed in a drum blender. The pressing parameters were the following: temperature 200 ºC, pressing time factor 20 s/mm of nominal panel thickness, and unit pressure 2.5 MPa.

Characterization of the panels

The modulus of elasticity (MOE) and the modulus of rupture (MOR) during bending were investigated according to EN 310:1993, the determination of tensile strength perpendicular to the plane of the board (Internal bond - IB) according to EN 319:1993, the determination of resistance to axial withdrawal of screws (screw withdrawal resistance - SWR) according to EN 320:2011. The following physical features of the panels have been investigated: swelling in thickness (TS) and water absorption (WA) after immersion in water in accordance with EN 317:1993, and surface absorption (SWA) according to EN 382-2:1993. The density profile (DP) has been measured on a GreCon DA-X unit, with sampling step 0.02 mm and with measuring speed 0.1 mm/s. As many as 10 samples have been used for all mechanical and physical features testing, except density profile, where 3 samples of every variant have been tested, and 2 samples per panel variant for surface absorption test. The achieved results have been referred to EN 622-5:2010.

Before testing, all the samples were conditioned in 20 °C/65% RH ambient air to achieve a constant weight.

The obtained results, where applicable, have been examined through the analysis of variance (ANOVA) and the Student's test has been completed ($\alpha = 0.05$) to determine the statistical significance of differences between the factors. The results presented in the plots show average values and standard deviations.

RESULTS AND DISCUSSION

The test results for the modulus of elasticity and modulus of rupture at static bending are presented in figure 1. The graph shows the relationship between the modulus of elasticity and the changes in the plant glue content. As it is shown, in the case of MOR, the lowest resination gives MOR about 32.2 N/mm^2, whereas the highest resination, 20%, leads to the highest MOR value, 42.9 N/mm^2. That means the MOR increase was about 34% (3.4% MOR increase per every % of resination increase) when referred to the minimum value. The MOR for the industrial glue (reference panel) was 43.1 N/mm^2. It is worth adding, that even the lowest resination by plant glue allows it to reach the MOR higher than required in European standard EN 622-5:2010. The only statistically significant differences between the average MOR value have been found between variants 10 and 12 vs. 20.

The MOE values presented in figure 1 represent the similar to MOR tendency of increase with plant binder content increase. The lowest MOE was 2780 N/mm^2, whereas the highest was 2883 N/mm^2. The MOE for the industrial glue panel was 2926 N/mm^2. The relative MOE increase with plan binder content increase was 3.7%. Also here, even the lowest resination by plant glue allows it to reach the MOE higher than required in European standard EN 622-5:2010. No statistically significant differences have been found between MOE average values.

A similar relation between the increasing MOR and MOE with raising resination has been found in the case of particleboards bonded with the use of industrial amine resin (Rzyska-Pruchnik and Kowaluk 2021), as well as in the case of hardboard (Wronka et al. 2020). However, according to Hong et al. (2017), the raising resination has not so significant influence on MOE, as it has on MOR values.

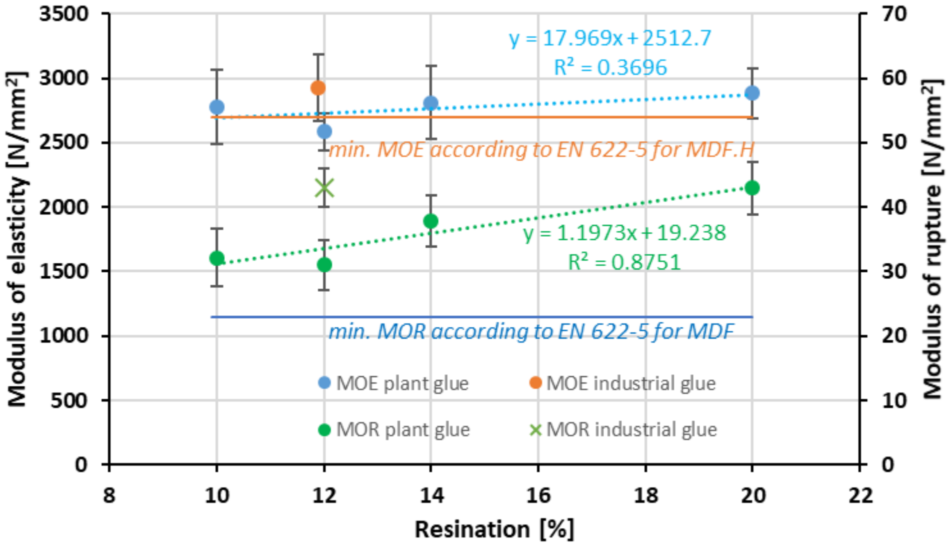

Figure 1. Modulus of rupture and modulus of elasticity of the panels of various content of plant binder

The results of measuring of influence of plant-based binder content on the internal bond of produced panels have been presented in figure 2. The results show that the resination increase causes a significant raise in IB, starting from 0.68 N/mm^2 for variant 10 to 0.88 N/mm^2 for variant 20, which means almost a 30% increase (about a 3% raise with a 1% resination increase). The IB for the reference panel bonded with UF resin was 0.79 N/mm^2. All the achieved values are higher than the requirements of EN 622-5:2010 standard. The only statistically significant differences between the average IB values have been found between variants 10 and 12 vs. 20.

Interesting results of IB tests when investigating the properties of low-density wood particleboards bonded with starch foam have been found by Monteiro et al. (2019). They prove, that with the increase of time of holding the pressed mat it the press, the IB of the tested panels significantly decreases. However, in the case of industrial amine resins, the IB raises with the resination raise to the maximum and then decreases with a further increase of resination. According to Rzyska-Pruchnik and Kowaluk (2021), for particleboards, this maximum IB for particleboards can be reached with a resination of about 30%.

The results of measuring of influence of plant-based binder content on the screw withdrawal resistance of produced panels have been presented in figure 3. The achieved results show that the rise in resination lead to a significant rise in SWR, starting from 116 N/mm for variant 10 to 144 N/mm for variant 20, which means almost a 24% increase (about a 2.4% raise with a 1% resination increase). The SWR for the reference panel bonded with UF resin was 169 N/mm, which means significantly higher, even when compared to variant 20 (the highest content of plant glue). The only statistically significant differences between the average SWR values have been found between variant 20 and vs. remaining variants.

The improvement of SWR of the medium density fibreboards with the increasing resination has been confirmed by Hong et al. (2017). Due to the fact, that in the mentioned research the industrial UF resin of the content of 8% - 14% has been used, it is impossible to refer the achieved results to those evaluated in this research.

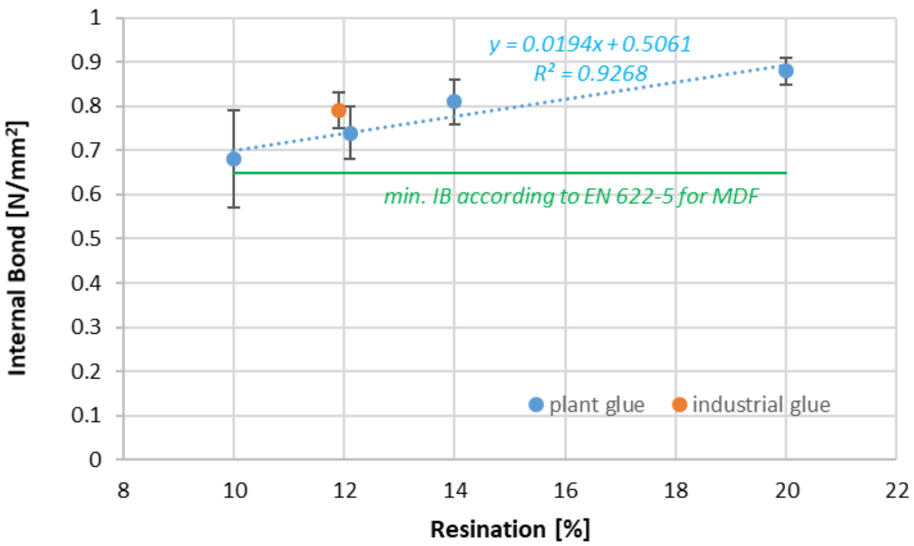

Figure 2. The internal bond of the panels of various content of plant binder

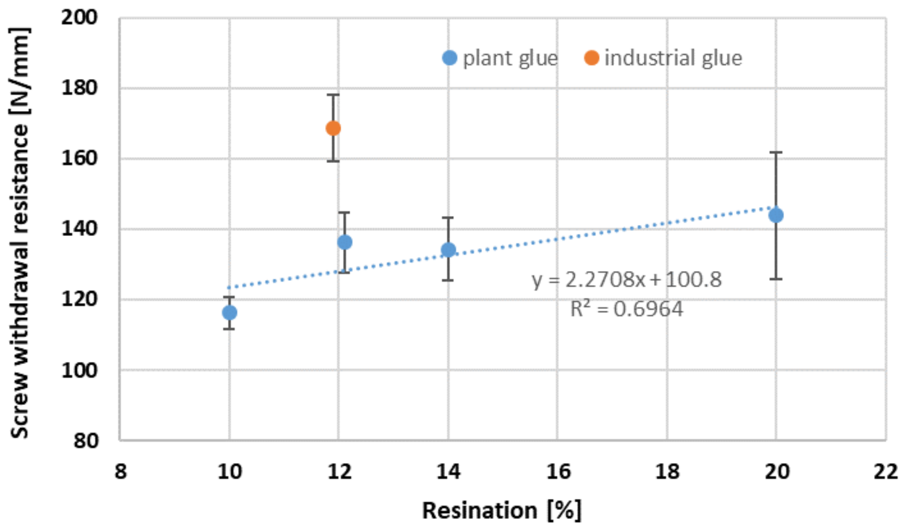

Figure 3. The screw withdrawal resistance of the panels of various content of plant binder

The results of measuring thickness swelling are presented in figure 4. The chart presents the relationship between thickness swelling and resination under the 2 h and 24 h of soaking samples in water. In the case of 2 h soaking, the rise of the resination by plant glue cause the reduction in TS for about 129% (when referred to as lower value), starting from 52.2% to 22.8% TS. After 24 h of soaking, the TS of samples of variant 10 was 55.4%, and 23.8% for variant 20. It should be pointed, out that the intensity of the final thickness increase when soaked in water, measured as the difference between the thickness after 2 h and 24 h of soaking, increasing with the binder content increase. The TS of reference samples with industrial binder was 27.9% and 28.4%, after 2 h and 24 h of soaking, respectively. The only samples of 14% and 20% resination meet the requirements of EN 622-5:2010 standard. However, by analyzing the regression lines, it can be concluded, that the resination of 14% is the minimum to meet the mentioned standard requirements. All the achieved average values of TS are statistically significantly different from one another.

As has been confirmed by other researchers (Antov et al. 2021), the TS is one of the crucial parameters that characterize the further way of application of wood-based composite. The reduction of TS with an increase in resination by plant glue (starch) has been confirmed by Wronka et al. (2020).

The relations between the binder content and water absorption, presented in figure 5, are the same as in the case of TS. Here, it can be pointed out, that the differences between the WA after 2 h and 24 h of soaking are much higher for panels of lower resination. All the achieved average values of WA are statistically significantly different from one another.

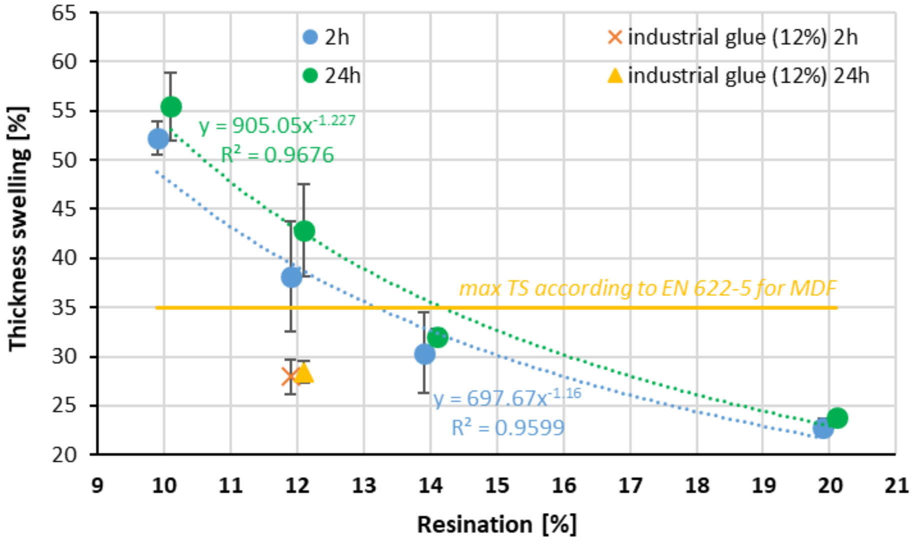

Figure 4. The thickness swelling of the panels of various content of plant binder

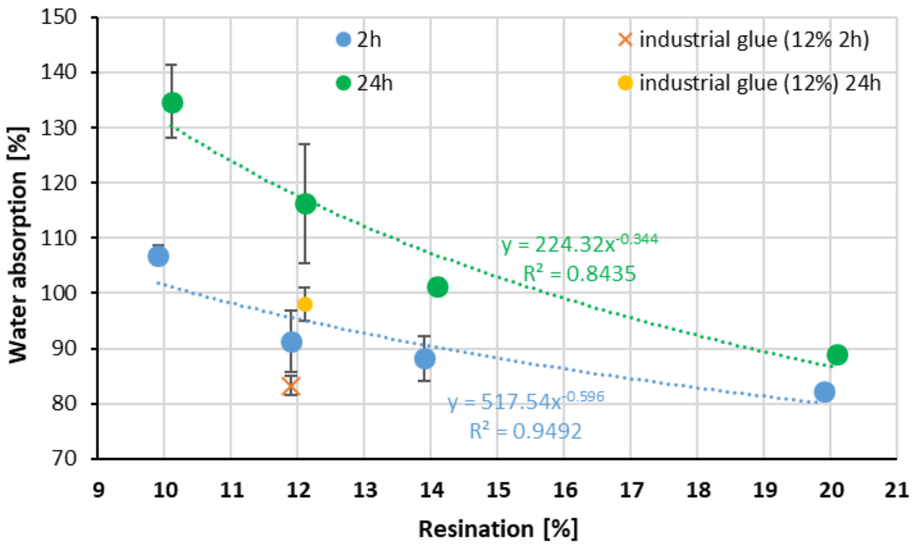

Figure 5. The water absorption of the panels of various content of plant binder

The results of surface water absorption of the panels of various binder content have been presented in figure 6. As can be seen, the SWA significantly decreases from 5318 g/m^2 for variant 10 to 2704 g/m^2 for variant 20, which means an almost 97% reduction when referred to a lower value. The SWA of the panel with industrial glue was 3603 g/m^2. According to the achieved results, it can be said that the SWA level can be achieved for plant binders with a resination of about 14%. The reduction of SWA with the resination increase should be considered very positively, since, according to Sala et al. (2020), this parameter is crucial in light of further surface finishing.

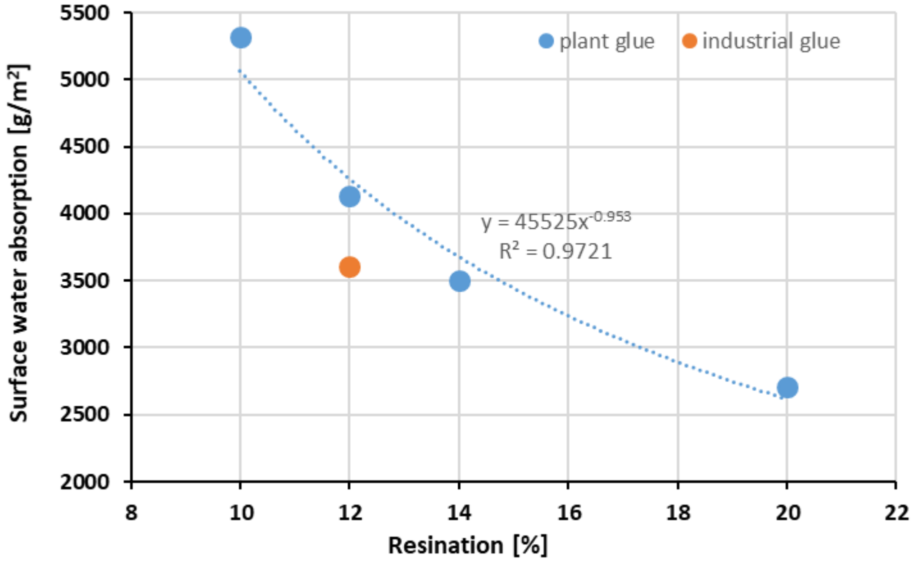

Figure 6. The surface water absorption of the panels of various content of plant binder

The results of measuring of density profile for panels of raising plant glue resination in the MDF board are presented in figure 7. The highest values of density have been reached for the face layer zone located at two different thicknesses, 0.4 mm and 2.7 mm. The highest values of density reach over 900 kg/m^3 for industrial glue and 12% resination. However, also for industrial glue panels the lowest values of density, below 700 kg/m^3, have been found. This can be the reason for quite low values of internal bond when referring to the values of plant glue panels. It can be concluded, that with increasing plant glue resination, the differences in density between the face and core layer decrease, which means, the density profile goes to become flattered.

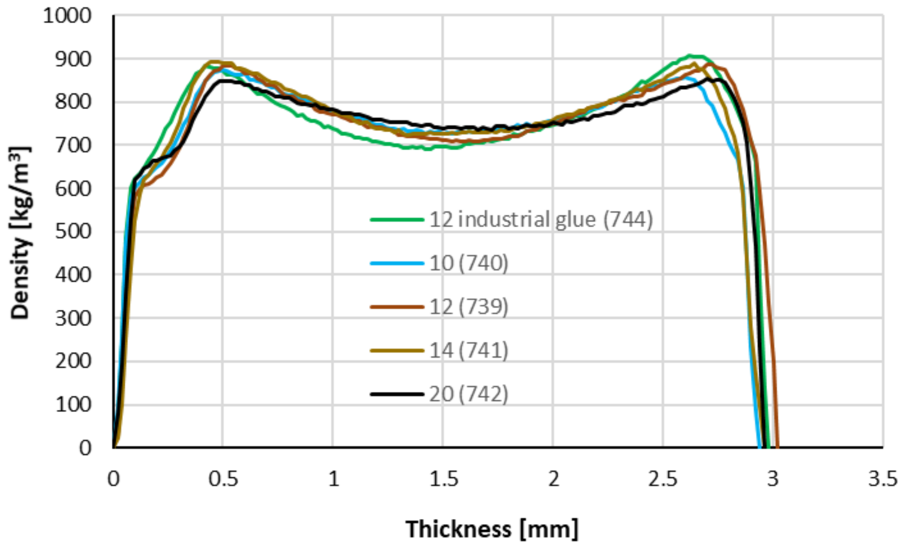

Figure 7. The density profiles of the panels of various content of plant binder

CONCLUSIONS

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

- Bending strength significantly grows with plant glue resination, reaching values that meet the minimal requirements of the proper European standards.
- The modulus of elasticity raised insignificantly with plant glue resination raise and reached values that meet the minimal requirements of the proper European standards.
- The internal bond values and screw withdrawal resistance were raising with increasing resination. the reason for increasing IB can be a modified density profile.
- The thickness swelling, water absorption, and surface water absorption decrease with the plant glue raising resination, and it was proven, that with the use of reasonable resination.
- With increasing plant glue resination, the differences in density between the face and core layer decrease.
- Except for screw withdrawal resistance, it is possible to reach the panels' parameters comparable to the panels produced by regular, industrial amine resin.

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Streszczenie: *Wybrane cechy płyt pilśniowych średniej gęstości wytwarzanych z użyciem spoiwa roślinnego*. Celem badań było określenie możliwości produkcji płyt pilśniowych suchoformowanych z wykorzystaniem różnego udziału kleju roślinnego, jako środka wiążącego. Zakres prac obejmował wytworzenie płyt w warunkach laboratoryjnych przy: 0%, 10%, 12%, 14% i 20% udziale masowym kleju roślinnego oraz poddanie ich wybranym próbom fizycznym i mechanicznym. Potwierdzono możliwość wytwarzania płyt pilśniowych suchoformowanych (typu MDF) z wykorzystaniem kleju roślinnego.

Słowa kluczowe: płyta pilśniowa, MDF, klej roślinny, spoiwo, zaklejenie

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