Annals of Warsaw University of Life Sciences – SGGW
Forestry and Wood Technology № 114, 2021: 59-69
(Ann. WULS-SGGW, For. and Wood Technol. 114, 2021: 59-69)

Application of beeswax as a hydrophobic agent in MDF technology

KRZYSZTOF KRYŃSKI[1], GRZEGORZ KOWALUK[2]

[1]Faculty of Wood Technology, Warsaw University of Life Sciences - SGGW
[2]Department of Technology and Entrepreneurship in Wood Industry, Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW

Abstract: *Application of beeswax as a hydrophobic agent in MDF technology.* The aim of this study was to investigate the possibility of using beeswax as a hydrophobic agent in MDF board technology. In scope of the work, dry-formed fibreboards in four variants of wax content were produced under laboratory conditions: 0; 0.5; 1 and 5%, and boards with 1% of industrial hydrophobic agent. Produced boards were tested for selected physical and mechanical properties. Obtained results proved that beeswax can be used as a sterling hydrophobic agent. Furthermore, the tests confirmed an improvement in mechanical properties after the application of beeswax.

Keywords: beeswax, MDF, hydrophobic agent, paraffin

INTRODUCTION

Fibreboard is a wood-based material produced from plant-based materials with a fibrous structure. These boards are mainly made from wood harvested from forests: e.g. small- and medium-sized wood (raw material for the paper industry), wood waste (mainly sawdust from sawmills, sawn timber offcuts and plywood rollers from plywood factories), wood chips from raw materials obtained in forests and annual plants (cereal straw, bagasse, stems of cotton) (Sala et al. 2020; EN 316:2009).

Fibreboards are made using two methods: dry and wet. In the dry method, air acts as the fibre carrier, whereas in the wet method, water acts as the fibre carrier. The wet method produces softboards and hardboards depending on degree of compression, while the dry method produces MDF (LAUROW 1999).

However, several types of dry formed boards can be distinguished, which is related to their density. These are lightweight boards (below 650 kg/m^3), MDF (650-800 kg/m^3), HDF (above 800 kg/m^3) (WNOROWSKA et al. 2017).

The basic components of wood contain hydrophilic elements in their structure, from among carboxyl (-COOH) and hydroxyl (-OH) groups can be distinguished. Wood in the form of chips or fibres has a greater tendency to absorb water compared to the original raw material. In order to minimise water absorption in finished boards, hydrophobic agents were added to the wood in chipped form to prevent water from entering the board (FAN et al. 2009).

Classical hydrophobic sealing, which simultaneously increases strength, consists in introducing hydrophobic agents into the fibre mass, usually in the form of an emulsion, or spraying the wet web with an emulsion or oil just before pressing at high temperature (BOROWSKI et al. 1965).

In many cases, coumarone resin, waxes, or asphalt have been used as hydrophobic agents (ONIŚKO 1978). However, the above-mentioned products cause a decrease in the value of the mechanical properties of wood-based panels. A substance of hydrophobic character, which does not cause a decrease in strength, is rosin in combination with aluminium salts. The most commonly used was pine rosin (BOROWSKI et al. 1965).

A currently used hydrophobic agent in the production of wood-based panels is paraffin, usually in the form of an aqueous emulsion. Another agent used for this purpose is barisol slack, which is a product created by distillation and rectification of paraffin from crude oil (ONIŚKO 1978).

A substance of natural origin with similar hydrophobic properties to paraffin is beeswax.

Beeswax is insoluble in water and resistant to many acids. It is soluble in most organic solvents such as acetone, ether, benzene, xylene, toluene and many others. However, at room temperature it does not dissolve completely in any of the above solvents. In order for wax to dissolve completely in them, it must be heated to a temperature above its melting point (under these conditions it is also soluble in ethanol) (TULLOCH 1980).

The aim of this work was to use beeswax as a hydrophobic agent in MDF technology. In the scope of research, the beeswax emulsion has been prepared, and the set of MDF panels of different hydrophobic agents and their content has been produced in laboratory conditions. These panels have been tested to characterize their selected mechanical and physical properties.

MATERIALS AND METHODS

The research material consisted of laboratory-made MDF boards with an assumed density of 750 kg/m^3, 320 mm x 320 mm and nominal thickness of 3 mm, where beeswax in the form of an aqueous emulsion was added at the production stage in three different mass proportions. The assumed 3 mm panel thickness (remarkably lower than regular commercial MDF panels) has been chosen due to the ability of better characterization of panels' reaction to water. The raw materials listed below were used to make the tested material:

- Industrial fibre mass for MDF production, moisture content 4%
- Urea-formaldehyde resin Silekol S123 with the concentration of 65% and dedicated industrial hardener; gel time of the adhesive mass at 100°C approx. 82 s, resination 12%
- Hydrophobic agent - 1) beeswax, taken from own bee-garden, for this research in the form of an aqueous emulsion (15% aqueous beeswax emulsion obtained by adding emulsifier - sodium tetraborate ($Na_2B_4O_7$)) or 2) industrial paraffin emulsion with a concentration of 50% for the production of reference boards
- pressing temperature 200°C, pressing factor 40 s (in reference to gel time of adhesive mass), unit pressing pressure 2.5 MPa

Five variants of MDF boards were made for the tests:

- Reference MDF boards were produced with an industrial paraffin-based hydrophobic agent
- MDF boards without hydrophobic agent
- MDF boards with 0.5% beeswax emulsion
- MDF boards with 1% beeswax emulsion
- MDF boards with 5% beeswax emulsion

Density

The density determination was carried out in accordance with a standard EN 323 on at least 10 samples in each variant.

Density profile

Determination of the density profile has been carried out on a GreCon DA-X device, which uses X-rays during the analysis. There were placed 3 samples for each variant in the analyser with determined dimension (50x50x thickness, mm^3). The measurement interval was 0.02 mm and the measurement speed was 0.05 mm/s.

Thickness swelling

Thickness swelling was tested in accordance with a standard EN 317 on at least 10 specimens for each variant. Thickness measurements of the samples after 2 and 24 hours of soaking in water were carried out.

Water absorption

Water absorption determination was carried out after 2 and 24 h of soaking in water when measuring the thickness swelling. The test was carried out on at least 10 samples per variant. Absorbability calculations were made based on relation (1):

$$WA = \frac{m_2 - m_1}{m_1} x100\ [\%] \tag{1}$$

where: WA-water absorption [%], m_1 *- mass of sample before soaking in water [g],* m_2 *- mass of sample after soaking in water [g].*

Surface absorption

The determination of the surface absorption was carried out in accordance with a standard EN 382-2 on two samples for each variant. The several samples of the different board variants were surface-irrigated for two hours.

Static Modulus of Elasticity and Modulus of Rupture

Static Modulus of Elasticity and Modulus of Rupture testing was carried out in accordance with a standard EN 310 on at least 10 specimens from the variant.

Statistical analysis

One-way variance analysis (ANOVA) has been completed to study the influence of various hydrophobic agents on the properties of the investigated panels at the significance level α = 0.05. The statistical analyses have been performed using the software of IBM SPSS Statistics 22.

All the mean values of the tested features (where applicable), standard deviations and statistical analyses results have been collected in tab. 1.

RESULTS

Analysis of density determination results

The results of the density determination are shown in fig. 1. The results of the arithmetic mean, calculated on the basis of the analysis of a series of values obtained during the testing of fibreboard samples with beeswax in several variants, are presented. The values of the average density did not differ significantly from the assumed value and were close to the literature values (WNOROWSKA et al. 2017). Differences between variants ranged from 0.53 to 21.66 kg/m^3, which is from 0.07% to 2.88% of the nominal value. In the variant with 1% hydrophobic agent content, the value of the average density is slightly higher for the boards with paraffin compared to the boards with beeswax, with a difference in average density of 2.93 kg/m^3. The standard deviation for the density of the boards without beeswax addition is higher compared to the other variants. The smallest standard deviation of density could be seen in the board with 1% beeswax content. A slight increase in density with increasing beeswax content can be observed. Based on the analysis of the obtained results of the density of the tested boards, it can be concluded that the differences in the average values of the density of the boards for several variants are not statistically significant.

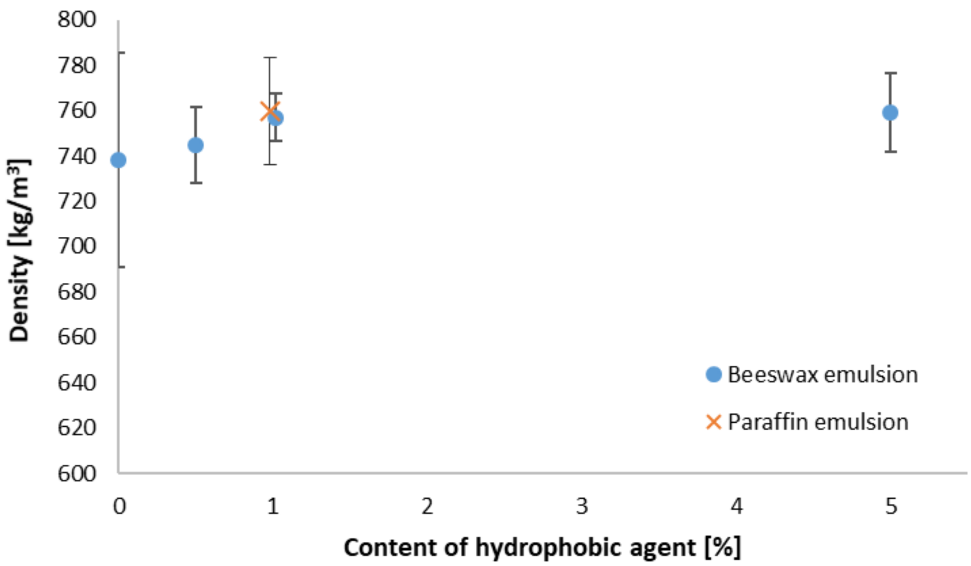

Fig. 1 Density of the tested panels

Analysis of the density profile determination

Fig. 2 shows the distribution of the results of determining the density profile of the tested boards with different percentage of beeswax and the reference boards. Due to the repeatability of test results for a series of tested samples, single samples for each variant were isolated. Due to the symmetrical character of changes in the density profile regarding to the centre of board thickness, half of the graph from the surface to the centre of thickness was presented for better readability. The density profile for the control variant with industrial agent and without the contribution of the hydrophobic agent differs significantly compared to MDF boards with the contribution of wax. The results in the graph show that for the boards with wax emulsion participation, the density of the face layers is higher than in the core layers. A similar shape of the density profile graph was obtained when testing with melamine polypropylene wax (ROSILEI et al. 2005) and when testing particleboards made of bamboo (SUMARDI and SUZUKI 2014). In addition, it can be observed that as the mass proportion of beeswax in the studied boards increases, the density of the external layers decreases, although for the highest studied proportion of beeswax (5%) a significant increase in the density of the board's surface layers is visible. Considering the boards without beeswax as well as with a mass share of 1% of the industrial agent, the highest densities are found in the middle of the board thickness, while in the face layers they take on the lowest values. This may be related to the easier migration of the paraffin during pressing the boards at 200°C together with the heat flow from the direction of the press shelves towards the middle of the thickness of the pressed material. Paraffin has a lower melting point (depending on the paraffin type it can be as low as 45-50°C) and a lower density (approximately 900 kg/m^3) (FREUND and MÓZES 1982) comparing to the beeswax, which has a melting point of 62-72°C and a density of 954-969 kg/m^3 (BORNUS 1989).

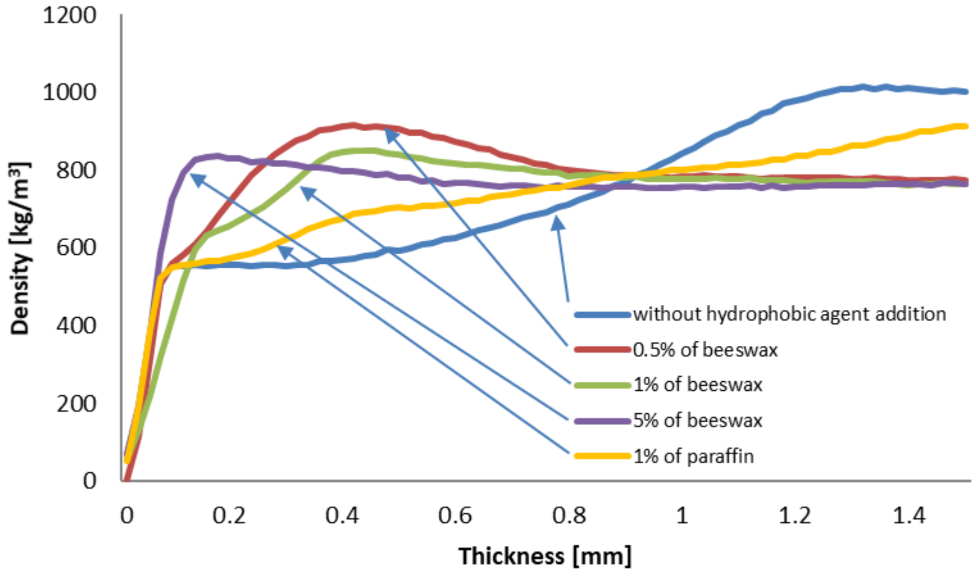

Fig. 2 Density profile of tested panels

Analysis of water absorption test results

The results of water absorption test are shown in fig. 3. On the basis of the analysis of the obtained results, a significantly lower absorption can be observed with an increase in beeswax content. The boards with 5% beeswax content were characterised by the lowest absorption. Compared to the boards without the presence of the hydrophobizing agent during a 2-hour soaking in water, the results obtained for the samples of the 5% variant were over 5.5 times lower and amounted to less than 18% of the absorption of the control samples. After 24 hours of soaking in water, the absorption for the 5% variant samples was more than 2 times lower than that in the control samples and was below 47% for the tested panels without beeswax. Similar values for absorbability were found for MDF boards when tested with different types of paraffin in the study by ROFFAEL et al. (2005). Based on the analysis of the absorbability results obtained for the tested boards it can be observed that the differences in average absorbability values of boards of particular variants with beeswax after a 2h soaking are not statistically significant for variants 1, 5 and 1% with paraffin. However, the difference in average absorbability values after 2 hours for the 0.5% beeswax variant and other variants with beeswax is statistically significant. After 24h of soaking, the differences in absorbability results of variants 0, 0.5, 1% are statistically significant. The difference in average water absorption values of variant 1 with beeswax and paraffin and variant 5 are not statistically significant. The results of testing the absorbability of variants of boards with a 1% content of beeswax and paraffin show a slightly higher efficiency of beeswax as a hydrophobic agent, which manifests itself in lower absorbability of these boards, although the differences in average values are not statistically significant.

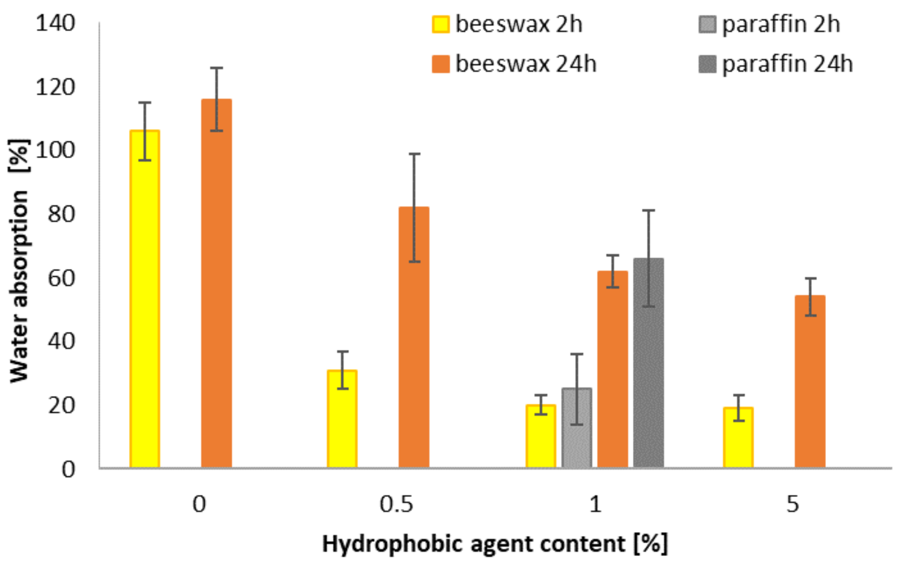

Fig. 3 Water absorption of tested panels

Analysis of thickness swelling test results

The results of the thickness swelling determination are presented in fig. 4. Interpreting the results of 24-hour humidification in water it is impossible not to notice that with increase in beeswax content the average thickness swelling of the tested boards decreases to 1% of beeswax content, while at 5% of beeswax the swelling slightly increases. When comparing the control samples with samples with 1 percent of beeswax, it can be observed that the thickness swelling for the 1 percent variant is 30% lower than for the samples without beeswax. Lower values of swelling results after 24, comparing to MDF boards with beeswax participation at 1%, were obtained during the research conducted by GRIGSBY and THUMM (2011), however, using thicker MDF boards and application of emulsified Mobilicer 538 wax. On the other hand, comparable swelling results after 2 and 24h were obtained by ROFFAEL et al. (2005) during a study in which 3 types of paraffin with different chemical compositions were used, and in a study of fibreboard with soy protein (XIN et al. 2009). A similar trend was obtained after 2 hours of soaking, but the exception was the 5% variant, for which the results obtained were at a similar level as for the 0.5% wax share variant. Comparison of the control sample with variant 1 shows that the samples with wax participation had average 70% less thickness swelling than in the boards without wax. Regarding the requirements of EN 622-5:2009 standard for panels to be used in dry conditions, analysing the mean thickness swelling after 24h of soaking, all the tested panels with any hydrophobic agent addition, including those with paraffin and beeswax, meet the requirements. Based on the analysis of the swelling results obtained for the tested boards, it may be determined that the differences in the average swelling values of particular variants after 2 hours of soaking are statistically significant for variants 0 and the others, 0.5 and the others, and after 24h of soaking for variants 0 and the others, and 0.5 and 1%. Statistically significant for 2 and 24 hours of soaking are the differences in swelling for a 1, 5% share of beeswax and 0%.

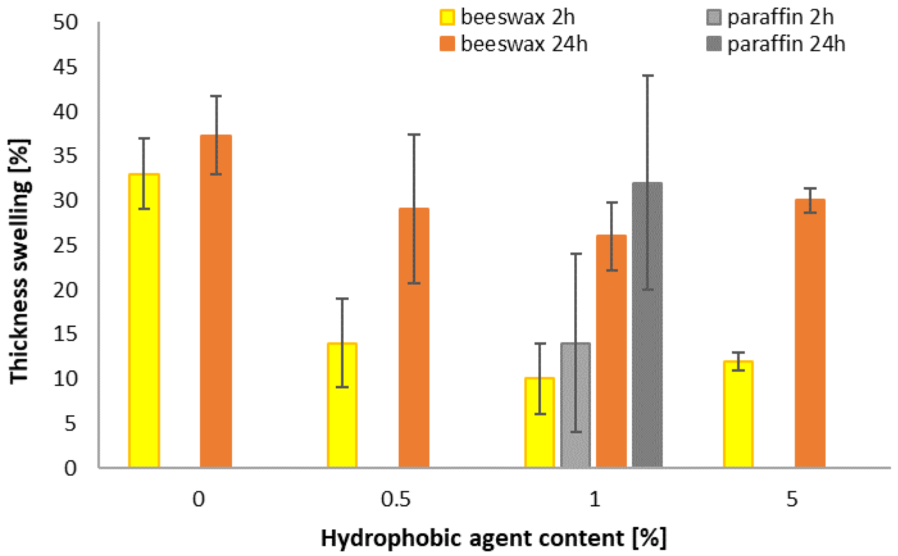

Fig. 4 Thickness swelling of tested panels

Analysis of the surface absorption results

The results of surface absorption tests are presented in fig. 5. While analysing obtained results, it is easy to notice a decreasing tendency of the surface absorption with an increase of beeswax content. For 1% variant, it can be seen that the board with paraffin shows lower surface absorption compared to the absorption of the board with a beeswax content. The board with 1% of paraffin has an average absorption value almost 95% lower than in the control sample. The data also shows that with 5% beeswax in fibreboard, the surface absorption decreases more than 94% compared to MDF without the hydrophobic agent. However, slightly better surface absorption results were achieved using different filler mixtures in order to reduce surface absorption and roughness (NICEWICZ and MONDER 2015). The smallest scatter of test results was noted for the 5% variant, and the standard deviation for these samples was 58 g/m^2. Apart from the variants with paraffin and 5% with beeswax, there were statistically significant differences between 1% paraffin, 5% beeswax and remaining panels.

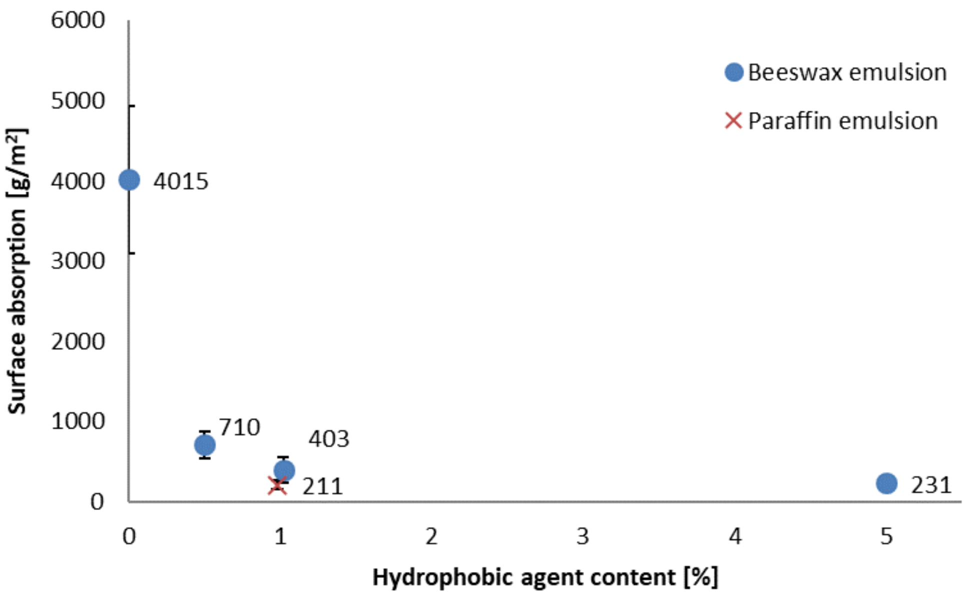

Fig. 5 Surface absorption of tested panels

Analysis of the results for Modulus of Elasticity and bending strength

The results obtained during the determination of the Modulus of Elasticity at static bending are included in fig. 6. While analysing the data showed in the graph, it is possible to notice an increasing trend of the average value of the modulus of elasticity with increasing beeswax content. The board with 1% beeswax content achieved a result slightly lower than the 0.5% variant board. The highest average value of the Modulus of Elasticity was obtained in the 5% variant. This value was 60% higher than in the control sample (without the hydrophobic agent). This result is lower than in the study of fibreboards carried out by XIN et al. (2009). Similar MOE results to the 5% variant were obtained for MDF containing cellulose nanocrystals in its composition (KHANJANZADEH et al. 2019). Based on the analysis of the obtained results of MOE at bending of the tested boards, it can be concluded that the differences in the average values of the Modulus of Elasticity of different variants are statistically significant in the case of variant 0 and the others, for 5% and the variant with paraffin.

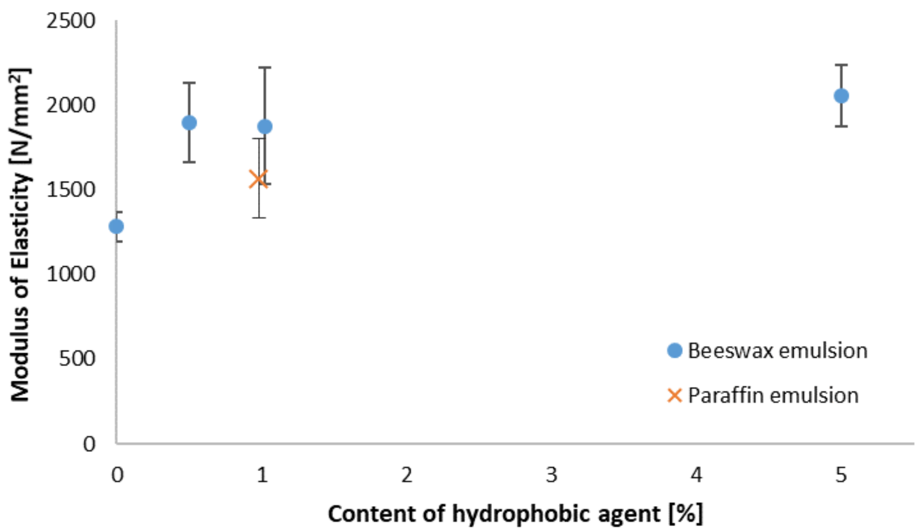

Fig. 6 Modulus of Elasticity of tested panels

A summary of the results of the static bending strength has been presented in the fig. 7. Interpreting the data obtained it can be noticed that the addition of beeswax causes an increase in bending strength up to wax content of 0.5%. However, after exceeding this percentage with an increase in the beeswax content, the bending strength decreases and in the case of the 5% variant the value is slightly lower than in the control sample, for which the difference in average values is 2.7%. The highest average MOR value was obtained for the 0.5% wax variant and was 55% higher than in the samples without beeswax. Similar results of average MOR were obtained when fibreboards with soy protein were tested (XIN et al. 2009). Regarding the requirements of EN 622-5:2009 standard for panels to be used in dry conditions, analysing the mean bending strength, the only panels with 0.5 and 1% of beeswax addition meet the requirements. The highest standard deviation in the boards with wax participation was observed in the 0.5% variant. It is also noticeable that the average MOR for the variant with 1% wax share is 31% higher than for the variant with 1% paraffin share. Based on the analysis of obtained MOR results for tested boards it can be concluded that the differences in the average strength values for particular variants are statistically significant in the case of variants 0.5 and 0; 0.5 and 5% and also for 1% of beeswax and 1% with a share of paraffin emulsion.

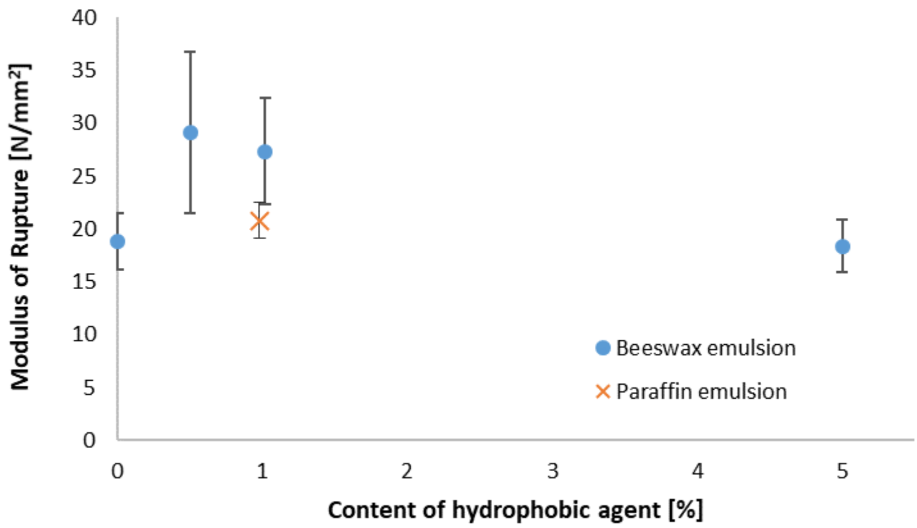

Fig. 7 Modulus of Rupture of tested panels

Tab. 1 Table of results

Feature	Content of hydrophobic agent [%]				
	0	0.5	1	1 (paraffin)	5
Mean density [kg/m^3]	738^{a}* (47.2)	745^{a} (16.8)	757^{a} (10.4)	760^{a} (23.7)	759^{a} (17.3)
Water absorption 2h [%]	106^{a} (9)	31^{b} (6)	20^{c} (3)	25^{c} (11)	19^{c} (4)
Water absorption 24h [%]	116^{a} (10)	82^{b} (17)	62^{c} (5)	66^{c} (15)	54^{c} (6)
Thickness swelling 2h [%]	33^{a} (4)	14^{b} (5)	10^{b} (4)	14^{b} (10)	12^{b} (1)
Thickness swelling 24h [%]	37^{a} (4)	29^{a,b} (8)	26^{b} (4)	32^{a,b} (12)	30^{b} (1)
Surface absorption [g/m^2]	4015^{a} (911)	710^{b} (165)	403^{b} (161)	211^{b,c} (58)	231^{c} (15)
Modulus of Elasticity [N/mm^2]	1284^{a} (85.9)	1899^{b} (233.7)	1878^{b} (342.2)	1567^{b,c} (233.7)	2057^{b} (182.6)
Modulus of Rupture [N/mm^2]	18.8^{a} (2.7)	29.1^{b} (7.6)	27.3^{b} (5.0)	20.8^{a} (1.7)	18.3^{a} (2.5)

**standard deviations in parenthesis; a, b, c – common groups according to statistical analysis*

CONCLUSIONS

The results obtained from the testing of MDF boards with the use of beeswax as a water-repellent material have led to the following conclusions and observations:

1. Beeswax can be used as a substitute of paraffin, which is industrially used as a hydrophobic agent in MDF technology.
2. The proportion of beeswax has a negligible effect on board density, but has a more significant effect on the density profile where, at a comparable proportion to paraffin, it causes an increase in the density of the surface layers with a decrease in the density of the middle layers.
3. With increasing proportion of beeswax, there is an overall decrease in water absorption and swelling, which has a beneficial effect on the properties of the MDF board.

4. Beeswax in the mass proportion of up to 0.5% has a positive effect on the values of modulus of elasticity in static bending and bending strength in comparison with the control board and the MDF board with paraffin as a hydrophobic agent, but with an increasing proportion of beeswax in the examined range in the board structure, the value of bending strength and modulus of elasticity at bending strength decrease.
5. Surface absorption decreases with increasing amount of beeswax in the MDF board.

REFERENCES

BORNUS L. (red.) (1989): Encyklopedia pszczelarska, PWRiL, Warszawa

BOROWSKI W., DUDZIEC K., ODACHOWSKI L., OSIKA S., PŁOSZEK A., RODZEŃ K., WIERZBICKI A., ŻUKOWSKI L. (1965): Technologia płyt pilśniowych. Wydawnictwo Przemysłu Lekkiego i Spożywczego

EN 310:1993 Wood-based panels: Determination of modulus of elasticity in bending and of bending strength

EN 316:2009 Wood fibre boards - Definition, classification and symbols

EN 317:1993 Particleboards and fibreboards – Determination of swelling in thickness after immersion in water

EN 323:1993 Wood-based panels – Determination of densityEN 382-2:1993 Fibreboards – Determination of surface absorption - Part 2: Test method for hardboards

EN 622-5:2009 Fibreboards - Specifications - Part 5: Requirements for dry process boards (MDF)

FAN M., OHLMEYER M., IRLE M., HAELVOET W., ATHANASSIADOU E., ROCHESTER I. (2009): Performance in use and new products of wood based composites. Brunel University Press

FREUND M., MÓZES G. (1982): Paraffin products: properties, technologies, applications. Translated by Jakab, E. Amsterdam, The Netherlands: Elsevier

GRIGSBY W., THUMM A. (2011): The interactions between wax and UF resin in medium density fibreboard. European Journal of Wood and Wood Products 70(4); 507-517; DOI: 10.1007/s00107-011-0580-9

KHANJANZADEH H., BEHROOZ R., BAHRAMIFAR N., PINKL S., GINDL-ALTMUTTER W. (2019): Application of surface chemical functionalized cellulose nanocrystals to improve the performance of UF adhesives used in wood based composites - MDF type. Carbohydrate Polymers 206: 11–20

LAUROW Z. (1999): Pozyskiwanie drewna i podstawowe wiadomości o jego przerobie. Wydawnictwo SGGW: 359-361

NICEWICZ D., MONDER S. (2015): Influence of filling mixtures on the properties of HDF surface. Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology 89:112-115

ONIŚKO W. (1978): Technologia płyt pilśniowych. Wydawnictwo SGGW

ROFFAEL E., SCHNEIDER T., DIX B., BUCHHOLZ T. (2005): Zur Hydrophobierung von mitteldichten Faserplatten (MDF) mit Paraffinen Teil 1: Einfluss der chemischen Zusammensetzung des Paraffins und des Emulgatortyps auf die Hydrophobierung von MDF. Holz als Roh- und Werkstoff 63: 192–203

ROSILEI A. GARCIA, CLOUTIER A., RIEDL B. (2005): Dimensional stability of MDF panels produced from fibres treated with maleated polypropylene wax. Wood Sci Technol 39: 630–650

SALA C. M., ROBLES E., KOWALUK G. (2020): Influence of the Addition of Spruce Fibers to Industrial-Type High-Density Fiberboards Produced with Recycled Fibers. Waste and Biomass Valorization, (), 1-10; https://doi:10.1007/s12649-020-01250-8

SUMARDI I., SUZUKI S. (2014): Dimensional Stability and Mechanical Properties of Strandboard Made from Bamboo. BioResources 9(1), 1159-1167

TULLOCH A. P. (1980): Beeswax - Composition and analysis. Bee World 61 (2): 47-62

WNOROWSKA M. (red.), DZIURKA D., FIEREK A., MROZEK M., BORYSIUK P., HIKIERT M.A., KOWALUK G. (2017): Przewodnik po płytach drewnopochodnych. Wydanie II poprawione. Wyd. Stowarzyszenie Producentów Płyt Drewnopochodnych w Polsce

XIN L., YONGHUI L., ZHIKAI Z., DONGHAI W., JO A., KUICHUAN S., XIUZHI S. (2009): Mechanical and water soaking properties of medium density fibreboard with wood fiber and soybean protein adhesive. Bioresource Technology 100: 3556–3562

Streszczenie: *Zastosowanie wosku pszczelego jako środka hydrofobizującego w płytach MDF*. Celem badań było określenie możliwości wykorzystania wosku pszczelego jako środka hydrofobizującego w technologii płyt MDF. W zakresie pracy wytworzono w warunkach laboratoryjnych płyty pilśniowe suchoformowane w czterech wariantach zawartości wosku: 0; 0.5; 1 oraz 5%, oraz płyty z udziałem hydrofobizujacego środka przemysłowego o zawartości 1%. Wytworzone płyty zostały zbadane pod kątem wybranych właściwości fizycznych i mechanicznych. Uzyskane wyniki dowiodły, iż wosk pszczeli może być wykorzystywany jako pełnowartościowy środek hydrofobizujący. Ponadto badania potwierdziły polepszenie właściwości mechanicznych po zastosowaniu wosku pszczelego.
Słowa kluczowe: wosk pszczeli, MDF, środek hydrofobizujący, parafina

ACKNOWLEDGEMENT

Some actions to realize the mentioned research have been completed within the activity of Student Furniture Research Group (Koło Naukowe Meblarstwa) and Student Wood Technologists Research Group (Koło Naukowe Technologów Drewna), Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW.

Corresponding author:

Grzegorz Kowaluk
Department of Technology and Entrepreneurship in Wood Industry
Institute of Wood Sciences and Furniture
Warsaw University of Life Sciences – SGGW
Nowoursynowska Str. 159
02-787 Warsaw, Poland
email: grzegorz_kowaluk@sggw.edu.pl