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LIGHTWEIGHT BOARDS FROM WOOD AND RAPE STRAW PARTICLES

The study investigates the properties of lightweight (350–550 kg/m³) particleboards made using wood or rape particles and with veneers applied to their surfaces. Their suitability for the production of furniture and elements of interior design is discussed. Panels with veneer on their faces were made using a “one shot” pressing cycle. It was found that rape particles may be used for the production of lightweight particleboards, and that they are a good alternative to wood chips. Particleboards made of rape straw, covered with beech veneer during the pressing cycle in order to strengthen their subsurface layers, have better properties than the corresponding wood-chip-based particleboards. However, all the boards, throughout the whole density range, meet the requirements for P2 boards, i.e. boards intended for interior decoration and furniture production (MOR 11 N/mm², MOE 1600 N/mm², IB 0.35 N/mm² according to EN 312).

Keywords: particleboard, lightweight boards, rape straw, veneer, mechanical properties

Introduction

Constant growth in the production and consumption of wood-based boards, used mainly in the construction and furniture industry, has been observed for many years at a global and European level. The development of the furniture industry depends on easy access to timber, the global resources of which are limited. The continuing shortage of wood, its increasing price and the growing competition for this material between manufacturers of boards, the pulp and paper industry, and the energy sector using biomass, means that the demand of the wood-based boards industry for lignocellulosic materials can only be met in the coming years by recourse to the existing potential reserves, such as agriculture, especially the plantations of fast-growing or annual crops.

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Activities concerning the potential use of annual plants in the production of particleboards and fibreboards have been undertaken for many years. It is estimated that the resources of these plants significantly exceed the demand of the wood-based boards industry for lignocellulosic materials. Although the seasonality of supply, the need for storage, the low bulk density, and other negative aspects should be taken into account when using such materials, they should be considered an additional, but still high quality, resource. In recent years a lot of research projects have been conducted investigating the possibilities of using the waste of such plants as flax [Tröger, Ullrich 1994; Tröger et al. 1998], hemp [Girgoriou et al. 2000], sugar cane, rice straw [Yang et al. 2003], jute, grasses (*Miscantus*) [Tröger et al. 1998], cotton fibers [Guler, Ozen 2004], sunflower stalks [Khristova et al. 1998], vine prunings [Ntalos, Grigorou 2002], eucalyptus [Pan et al. 2007], evening primrose [Dukarska et al. 2010, 2012], mustard [Dukarska et al. 2011], Pennsylvanian mallow [Czarnecki et al. 2010], cereal straw [Sampathrajan et al. 1992; Hague 1997; Girgoriou 2000; Bowyer, Stockmann 2001; Pawlicki et al. 2001; Mo et al. 2003; Zhang et al. 2003; Boquillon et al. 2004; Zheng et al. 2007] and even rubberwood [Tongboon et al. 2002], bamboo [Papadopoulos et al. 2004], Scots pine needles [Nemli et al. 2008], and shells of coconuts [Papadopoulos et al. 2002], peanuts [Guler et al. 2008] and almonds [Gürü et al. 2006; Pirayesh, Khazaeian 2012].

The most interesting raw material, from among the wide range of above possibilities, which can be used for the production of particleboards, seems to be the straws of major cereal species, mainly because of their prevalence in any climate. The particular suitability of isocyanate adhesives for the manufacturing of this type of boards is due to the extremely good wettability of the straw surface facilitating the creation of a sufficient number of bonds between the individual particles [Mo et al. 2001; Boquillon et al. 2004]. Studies in this area have shown that straw or straw-chip particleboards produced according to the developed technologies and resinated with pMDI, exhibited higher static bending strength, better hydrostatic properties, and a smoother surface than boards produced from wood chips alone.

In the 1960s, the Polish Flaxboard Production Plant “Lenwit” in Witaszyce made its first attempts at manufacturing particleboards using rape straw. It was found that rape straw particles combined with wood chips were good quality materials for the production of particleboards, intended for insulation purposes. They were characterized by higher thermal insulating power, lower hygroscopicity and specific gravity. However, the high costs of material preparation and the lack of appropriate binding agents (with high adhesion forces) prevented the implementation of their regular production.

The chemical composition of rape straw is slightly different to wood [Dziurka et al. 2005]. Rape straw contains less cellulose and lignin, but more hemicelluloses and mineral compounds. Cellulose positively affects the mechanical pro-

properties of the boards, but the content of extraction substances is also important, as they determine the adhesion quality. The content of extraction substances in rape straw is slightly higher than the contents of such substances in wood, although – similarly to wood – they are dispersed throughout its mass. Therefore, in contrast to cereal straws, in which olefin substances are mostly accumulated on the surface and thus hinder resination, they should not have a disadvantageous effect on the gluability of rape straw particles, even if typical polar wood adhesives are applied.

Considering the literature data discussed above, it seems that the appropriate legal regulations and promotion of the idea among farmers could make rape straw a relatively easy and quick wood substitute.

Traditional particleboards with a mean density ranging from 650 to 720 kg/m³, have been used in the furniture industry for many years. However, in the light of new regulations and tendencies, the high density becomes an unquestionable disadvantage. The EU is expected to shortly introduce regulations, according to which the weight of a package containing elements designed for self-assembly cannot exceed 15 kg. Lightweight wood-based boards have been produced for a long time, and they are commonly used mainly in the construction industry, as insulating and soundproof material. However, due to poor mechanical properties, they have not been widely used for furniture production. The furniture industry is, to a large extent, based on honeycomb boards. Their layered structure with a honeycomb core provides a maximal reduction in weight without diminishing the load capacity, stiffness and other structural features. They are not, however, universal materials, and one of their most significant drawbacks is the need to use specialized machinery and equipment, special hardware and significant expenditure of labor.

Given the above, it was decided to investigate the possibility of the production of lightweight particleboards, that were refined by overpressing beech veneer in order to strengthen their subsurface layers. Additionally, in view of the wood deficit persisting over the last few years, it was also decided to assess the suitability of rape particles as an alternative raw material for manufacturing particleboards used for the production of furniture and interior design elements.

Materials and methods

In the board manufacture, commercial pine chips and rape straw particles obtained as a result of double shredding in a knife shredder were used together with peeled beech veneer with a thickness of 1.7 mm. The moisture content in the raw materials used in the tests was 2.5, 3 and 5.1%. Table 1 presents their basic parameters.

Table 1. The basic parameters of the raw materials used for the production of lignocellulosic boards*Tabela 1. Podstawowe parametry surowców stosowanych do wytwarzania płyt lignocelulozowych*

Parameter <i>Parametr</i>	Formula <i>Wzór</i>	Rape straw <i>Słoma rzepakowa</i>	Wood chips <i>Wióry drzewne</i>
Average dimensions <i>Średnie wymiary</i> l, b, a [mm]	–	15.02 × 1.30 × 0.97	12.45 × 1.87 × 0.83
Slenderness ratio <i>Smukłość</i>	$\lambda = \frac{l}{a}$	15.5	15.0
Flatness <i>Plaskość</i>	$\psi = \frac{b}{a}$	1.3	2.3
Specific surface <i>Powierzchnia właściwa</i> [m ² /kg]	$F_w = \frac{2}{\rho_0} \left[\frac{1}{l} + \frac{1}{b} + \frac{1}{a} \right]$	12.44	8.09

l, b, a – length, width, thickness

l, b, a – długość, szerokość, grubość

Two versions of lightweight wood and rape straw particleboards of densities 550, 500, 450, 400 and 350 kg/m³ were produced: single-layer particleboards and those with improved surfaces by the inclusion of decorative veneers (1.7 mm thick) in the surface layers. The 3-layer sandwich structure was hot-pressed together without applying a separate layer of adhesive to the veneers. The thickness of all the boards was 19 mm.

The raw and veneered boards were manufactured under laboratory conditions in 3 replications, applying the following pressing parameters:

- pressing time – 300 s,
- unit pressure – 2.5 N/mm²,
- temperature – 200 °C,
- resination rate for both wood and rape particle pMDI – 10 %.

The properties of the manufactured boards were tested following the respective standards:

- modulus of rigidity (MOR) and modulus of elasticity (MOE) according to EN 310 (parallel and perpendicular to the grain),
- internal bond (IB) according to EN 319,
- swelling in thickness (TS) after 24 h of soaking in water according to EN 317 and water absorption (WA).

In order to evaluate the mean value and standard deviation, 12 samples of each board were tested (the total number of samples being 36).

Additionally, for the veneered boards (550 kg/m^3), the density profiles were analyzed (laboratory density profile measuring system GreCon DA-X, measurement resolution 0.02 mm at a rate of 0.05 mm/s).

Results and discussion

The properties of the wood and rape straw particleboards with reduced density are shown in tables 2 and 3. As might be expected, the reduced density of the particleboards resulted in a lower bending strength and modulus of elasticity. Nevertheless, significantly better results were observed for rape straw particleboards. The strength of the particleboards with a density reduced to 350 kg/m^3 as compared to those with a density of 550 kg/m^3 , was only 18% for the wood chip boards and 32% for the rape straw boards. The modulus of elasticity tests yielded similar results.

Adding veneer to the particleboard surfaces greatly improved their properties, and some tests even showed a four-fold increase in strength compared to the raw particleboards (table 3). The veneered boards of either wood or rape particles met the requirements of EN 312 standard for P5 particleboards when the density was 450 kg/m^3 or greater (only parallel to the grain). This standard assumes that the bending strength and modulus of elasticity for load-bearing particleboards used in humid conditions should not be lower than 2400 N/mm^2 and 16 N/mm^2 . It should be additionally emphasized, that in respect of these properties, the requirements of this standard were even met by the rape straw particleboards with a reduced density of 350 kg/m^3 . As could be expected, the bending strength perpendicular to the grain in the surface layers was low due to a very weak natural wood strength in this direction (table 3).

As shown by the study results, the manufactured boards displayed good strength perpendicular to the plane of the board. Reducing the density was in fact accompanied by a decrease in strength, but the changes were not as sudden as in the case of the bending strength. It was further observed that the strength of the boards with the lowest density amounted to an average 38% of the strength of the highest density boards for both types of particles. Finishing the board surface with veneer did not improve this property and the strength of those boards was in fact similar to that of the raw boards.

Table 2. Mechanical and physical properties of raw particleboard and rape straw boards
Tabela 2. Mechaniczne i fizyczne właściwości surowych płyt z wiórów drzewnych i cząstek rzepaku

Density Gęstość		MOR f_m	MOE E_m	IB f_t	TS G_t	WA Nasiąkliwość
Target Założona	Measured Zmierzona					
kg/m ³		%				
Raw particleboard Płyta wiórowa						
550	510 (21*)	14.4 (2.1)	2370 (370)	1.00 (0.11)	11 (3.5)	96 (4.8)
500	465 (20)	8.51 (1.7)	1570 (110)	0.90 (0.09)	9.6 (1.9)	101 (5.2)
450	425 (12)	6.65 (0.8)	1270 (90)	0.62 (0.08)	9.3 (1.2)	115 (6.2)
400	365 (25)	3.77 (0.6)	710 (80)	0.48 (0.09)	8.1 (1.4)	132 (7.6)
350	320 (16)	2.56 (0.4)	360 (80)	0.35 (0.08)	7.0 (1.3)	139 (8.2)
Raw rape straw board Płyta z cząstek rzepaku						
550	495 (23)	12.7 (2.3*)	2330 (390)	0.82 (0.10)	14 (3.6)	49 (8.9)
500	460 (22)	9.38 (1.3)	1970 (70)	0.69 (0.09)	14 (2.1)	50 (9.7)
450	420 (20)	8.37 (0.7)	1630 (290)	0.64 (0.09)	14 (1.3)	55 (8.2)
400	370 (12)	5.47 (0.5)	1180 (180)	0.45 (0.10)	13 (1.6)	68 (9.2)
350	330 (14)	4.09 (0.6)	900 (110)	0.35 (0.04)	12 (1.1)	72 (11.3)

* standard deviation, * odchylenie standardowe

MOR – modulus of rigidity, f_m – wytrzymałość na zginanie

MOE – modulus of elasticity, E_m – moduł elastyczności

IB – internal bond, f_t – wytrzymałość na rozciąganie prostopadle do płaszczyzn płyty

TS – thickness swelling, G_t – spęcznienie

WA – water absorption, nasiąkliwość

Table 3. Mechanical and physical properties of veneered particle- and rape straw boards
Tabela 3. Mechaniczne i fizyczne właściwości formirowanych płyt z wiórów drzewnych i cząstek słomy rzepakowej

Density Gęstość		MOR f_m	MOE E_m	MOR f_m	MOE E_m	IB f_i	TS G_r	WA Nasiąkliwość
Target Założona	Measured Zmierzona							
kg/m ³		N/mm ²						
Veneered particleboard Formirowana płyta wiórowa								
550	525 (21*)	49.2 (2.7)	7050 (440)	12.2 (1.6)	1620 (280)	0.96 (0.11)	12 (3.6)	86 (5.3)
500	495 (20)	40.5 (1.5)	6600 (180)	8.85 (1.1)	1210 (170)	0.84 (0.10)	12 (2.9)	921 (5.9)
450	450 (12)	32.4 (1.8)	6010 (250)	6.52 (0.7)	970 (90)	0.66 (0.08)	11 (1.7)	98 (5.8)
400	420 (25)	24.4 (1.1)	4840 (190)	5.05 (0.5)	810 (90)	0.48 (0.09)	9 (1.3)	111 (6.3)
350	380 (16)	14.5 (0.8)	4390 (140)	4.93 (0.3)	480 (60)	0.37 (0.07)	9 (1.4)	120 (5.6)
Veneered rape straw board Formirowana płyta z cząstek rzepaku								
550	510 (15*)	51.0 (1.9)	7910 (410)	13.5 (1.2)	1860 (180)	0.85 (0.11)	13 (3.4)	66 (6.0)
500	465 (19)	47.4 (1.7)	6960 (390)	11.3 (0.9)	1660 (230)	0.76 (0.10)	11 (2.0)	69 (8.2)
450	425 (17)	42.5 (1.2)	7120 (210)	8.17 (1.1)	1340 (190)	0.64 (0.09)	10 (1.3)	82 (8.6)
400	360 (18)	36.5 (1.1)	6090 (410)	6.63 (0.8)	1050 (70)	0.49 (0.07)	9 (1.0)	88 (8.3)
350	320 (12)	30.8 (0.9)	5620 (340)	5.64 (0.6)	840 (60)	0.38 (0.06)	9 (1.2)	95 (6.8)

* standard deviation, * odchylenie standardowe,

MOR – modulus of rigidity, f_m – wytrzymałość na zginanie,

MOE – modulus of elasticity, E_m – moduł elastyczności,

II – parallel, \perp – perpendicular to grain, II – równoległe, \perp – prostopadłe do przebiegu włókien

IB – internal bond, f_i – wytrzymałość na rozciąganie prostopadłe do płaszczyzn płyty

TS – thickness swelling, G_r – spęcznienie,

WA – water absorption, nasiąkliwość

Summing up, the study results revealed that the manufactured particleboards met the IB strength requirements for P5 boards, regardless of the type of particles and method of surface finishing, with the exception of the lowest density boards (350 kg/m^3). As shown in tables 2 and 3, the tensile strength perpendicular to the plane of those boards was higher than 0.45 N/mm^2 .

The tests concerning swelling and water absorption showed that even though the swelling fell with decreasing density, it was accompanied by a significant increase in water absorption. This was due to the more porous structure of the lower density boards, which on the one hand reduced its tendency to swelling, and on the other hand improved its ability to absorb water. As could be expected, applying the veneer to the faces moderated water penetration into the boards, resulting in a reduced water absorption of the refined boards by an average of 12%, compared to the corresponding raw boards.

It was found that the rape particles may be used for the production of lightweight particleboards, and that they are a good alternative for wood chips. Particleboards made of rape straw and covered with beech veneer during the pressing cycle in order to strengthen their subsurface layers, had better properties than the corresponding wood-chip-based particleboards. While the rape straw particleboards met the requirements for P5 boards (16 N/mm^2 and 2400 N/mm^2) concerning their mechanical properties (MOR and MOE parallel to grain) even at the lowest density, the wood chip particleboards met those requirements only down to the density of 450 kg/m^3 . However, both types of boards with a density of 350 kg/m^3 met the requirements for the boards used for interior decoration and furniture production (type P2 – 11 N/mm^2 according to EN 312). In the case of the boards intended for furniture production, another important factor was the peeling resistance of the subsurface layers. This feature was particularly important for boards with a surface covered with a veneer during the board manufacturing cycle, without using an additional adhesive layer. Again, better results were obtained for the rape straw boards. The density profiles of the veneered boards presented in fig. 1 showed a clearly visible zone of reduced density at the veneer-board interface in the wood chip particleboards, which would result in a lower peeling resistance of this layer. The density profiles of the rape straw particleboards were quite different. The data presented in fig. 1 clearly showed a significant increase in density at the veneer-board border. It was therefore highly probable that this interface would not be the weakest point of the board.

These different density profiles may be due to the fact that the presence of waxes in straws of different origins hinders pMDI penetration, thus allowing for better coverage of their surface with resin [Liu et al. 2004]. This way the surface of the straw particles is covered by a uniform adhesive layer which determines the formation of effective bonds. This fact, combined with the higher plasticity of the rape particles and lower bulk density as compared to the wood chips, resulted in a much higher density of rape straw boards after compression to the same thi-

ckness. In rape straw boards the contact area of straw particles and veneer significantly increased, which undoubtedly improved their bonds. The situation was different in the case of wood chips. Their structure is dissimilar, more porous as compared to rape straw and they are not covered with waxes [Roll et al. 1990; Roll, Roll 1994; Shi, Gardner 2001]. pMDI penetrated into them, thereby weakening the adhesive-bonded joint between the chips and the veneer, which was reflected in the density profiles.

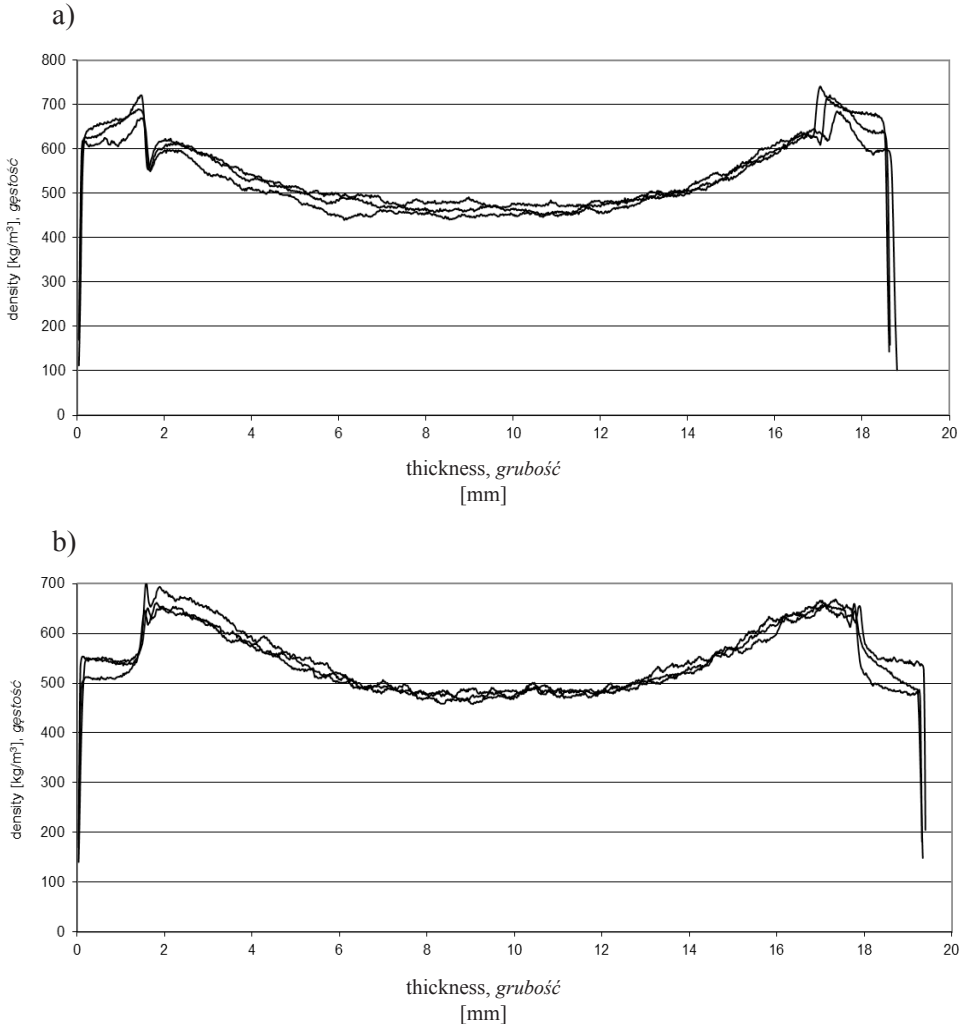


Fig. 1. Density profiles of veneered particleboard (a) and rape straw board (b) with density 550 kg/m³

Rys. 1. Profile gęstości fornirowanych płyt z wiórów drzewnych (a) i cząstek rzepaku (b) o gęstości 550 kg/m³

Conclusions

The conducted studies show that rape particles may be used for the production of lightweight particleboards, and that they are a good quality alternative to wood chips. Particleboards made of rape straw, that were covered with beech veneer during the pressing cycle in order to strengthen their subsurface layers, had better properties than the corresponding wood-chip-based particleboards.

The main consumer of wood-based boards is the furniture industry. A wood deficit, persisting for a several years, has triggered the search for and utilisation of new raw materials that thus far have not been considered useful, or have been processed only in small amounts. The development and progress of the particleboard industry should not only mean quantitative and qualitative improvement, but it also involves introducing completely new products, offering an unprecedented level of quality, attractive properties and new areas of application. An additional advantage of these boards is a significantly reduced density, as compared to conventional particleboards with a mean density 650 kg/m³. Lighter boards mean lighter furniture, which is beneficial for its users, but also an increase in the competitiveness of the final product thanks to the easy and rapid implementation of the latest design trends. All things considered, it seems that the veneered rape straw particleboards, offering the discussed advantageous properties, perfectly match the existing trends. Therefore, it can be assumed that they will be used in interior decoration, including furniture production.

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- EN 310** [1993]: Wood-Based Panels. Determination of Modulus of Elasticity in Bending and of Bending Strength
- EN 312** [2011]: Particleboards – Specifications
- EN 317** [1993]: Particleboards and Fibreboards. Determination of Swelling in Thickness after Immersion in Water
- EN 319** [1993]: Particleboards and Fibreboards. Determination of Tensile Strength Perpendicular to the Plane of the Board

LEKKIE PŁYTY Z WIÓRÓW DRZEWNYCH I SŁOMY RZEPAKOWEJ

Streszczenie

Tradycyjne płyty wiórowe, charakteryzujące się średnią gęstością w granicach od 650 do 720 kg/m³, są materiałem od lat stosowanym do produkcji mebli. Jednak w świetle nowych przepisów i trendów wysoka gęstość staje się ich zdecydowaną wadą. Lekkie płyty na bazie drewna są już od dawna produkowane, ale szerokie zastosowanie znajdują przede wszystkim w budownictwie, jako materiał izolacyjno-głuszący. Z uwagi jednakże na niskie parametry wytrzymałościowe dotychczas nie są szeroko stosowane do produkcji mebli.

Biorąc to pod uwagę, postanowiono zbadać możliwość wytwarzania lekkich płyt z wiórow drewnnych, które w celu wzmocnienia warstw przypowierzchniowych poddano uszlachetnieniu w procesie prasowania formem bukowym. Dodatkowo, uwzględniając utrzymujący się już od kilku lat deficyt drewna, postanowiono również ocenić przydatność do tego celu cząstek rzepaku, jako alternatywnego surowca do wytwarzania płyt, które mogłyby znaleźć zastosowanie do produkcji mebli i elementów wyposażenia wnętrz.

Badaniom poddano płyty wiórowe oraz rzepakowe o gęstości 350–550 kg/m³, a uszlachetnianie ich powierzchni przeprowadzono metodą 1-cykliczną, w której dekoracyjny fornir naprasowywano w cyklu wytwarzania płyty. Do zaklejenia obu rodzajów wiórow zastosowano pMDI.

W wyniku przeprowadzonych badań wykazano, iż możliwe jest zastosowanie do wytwarzania lekkich płyt cząstek rzepaku, które mogą stanowić pełnowartościowy substytut wiórów drzewnych. Wytworzone z nich płyty, które w celu wzmocnienia ich warstw przy powierzchniowych oklejono w cyklu prasowania fornirem bukowym, charakteryzują się lepszymi właściwościami niż analogiczne płyty wiórowe.

Rozwój i postęp przemysłu płytowego, oprócz wzrostu ilościowego i polepszenia jakości wyrobów, polega również na wprowadzaniu na rynek zupełnie nowych produktów o niespotykanym dotychczas poziomie jakości, atrakcyjnych cechach użytkowych i nowych obszarach zastosowań. Dodatkowym atutem wytworzonych w ramach pracy płyt jest ich znacznie obniżona gęstość w stosunku do tradycyjnych płyt wiórowych. Lżejsze płyty oznaczają nie tylko lżejsze meble, co jest korzystne dla ich użytkowników, ale także zwiększają konkurencyjność gotowego produktu, dzięki łatwemu i szybkiemu wprowadzaniu najnowszych trendów wzorniczych. W tym stanie rzeczy wydaje się, iż fornirowane płyty z wiórów drzewnych i cząstek rzepaku, ze względu na ich korzystne właściwości, idealnie wpisują się w obowiązujące obecnie trendy. Pozwala to przypuszczać, iż będą one mogły znaleźć zastosowanie jako płyty przeznaczone do wyposażenia wnętrz, łącznie z meblami, gdyż w całym zakresie gęstości spełniają wymagania normy dla tego typu płyt (MOR 11 N/mm², MOE 1600 N/mm², IB 0,35 N/mm² wg EN 312 dla płyt P2).

Słowa kluczowe: płyta wiórowa, płyty lekkie, słoma rzepakowa, fornir, właściwości mechaniczne

