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THE INFLUENCE OF POST-PRODUCTION MATERIALS ON LIGHTWEIGHT WOOD FIBERBOARD PARAMETERS

The aim of this study was to produce a very low-density insulation wood fibreboard, in dry technology, with the use of post-production fibres. During the tests, different amounts of post-production fibres, coming from various stages of processing such as grinding, edges cutting, cutting to the required board size, milling and disqualification of faulty boards, were added to lightweight fibreboard. The amount of possible added post-production wood fibres strongly depends on the characteristic of the fibres and particles size distribution. The parameters of the lightweight board, the most influenced by the dimensions of the fibres used, are mainly thermal conductivity and compressive strength.

Keywords: insulations fibreboard, post-production materials, low density fibreboard, wood fibres, LDF, wood fibreboards

Introduction

In today's construction industry, there is a noticeable trend towards building energy-saving houses with the use of ecological materials. One of the ways of achieving this goal is using insulation materials, which are friendly to the environment, have good end-use properties but also are affordable [Korjenic et al. 2016]. Among the wide range of insulation materials, those of natural origin made of wood fibres deserve special attention, as their production, requires much less energy comparing to the production of artificial thermal insulation material, and they are produced from renewable sources [Bozsaky 2010, 2019]. Furthermore, they show low thermal conductivity, good acoustic insulation property, vapor permeability, and what is the most interesting advantage in the use of wood

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fibreboard, they have a relatively high thermal capacity [Bianco et al. 2017]. Low density fibreboard (LDF) produced in dry technology represents such insulation material. So far LDF has been produced in density range 110 – 220 kg/m^3 but due to the research project co-funding within sectoral program WoodInn implemented by the National Centre for Research and Development (NCRD), Steico, a leading manufacturer of insulation and construction materials, developed a product with a density of around 80 kg/m^3, glued with MDI, and produced using steam injection pressing. Very low density wood fibreboard has the physicomechanical parameters necessary for the application as insulation material and is possible to produce on the existing production lines. The development of lightweight insulation fibreboard allows to introduce savings on the consumption of the raw material and to conduct waste-free, ecological production. In addition, in the case of the production of faulty products which, for example, do not meet the specified parameters, they can be recycled into production by re-processing into wood fibres on a separate dedicated two-stage shredding system. The possibilities of utilization of used insulation boards, produced in wet technology, as secondary raw material was described by Nicewicz and Danecki [2010]. The reuse of the separate waste MDF fibres in the production of new MDF as the most apparent possible recycling pathway was introduced by Hagel et al. [2021]. The effects of recycled fibre content on the properties of medium density fibreboard were investigated by Lubis et al. [2018]. Possibilities for manufacturing insulation boards with the participation of recycled lignocellulosic fibres were investigated by Antov et al. [2019]. There is no literature about adding post-production fibres to very low density insulation fibreboards produced in dry technology

The use of wood dust and fine fibers in the manufacture of lightweight boards implies the need to pay special attention to the process of wood fibres gluing. According to the present state of the art and literature data, the process of fibers gluing is influenced by, among other things, the specific surface area of the fibres and their particles, which depends on their size and increases with their decreasing thickness and density [Bekhta and Hiziroglu 2002]. The amount of adhesive per surface is also important. In theory, the amount of adhesive per particle should be proportional to the size of its surface, and the adhesive droplets should be evenly distributed on the surfaces of the wood material particles. In practice, however, always the process of gluing involves heterogeneous material with different dimensions, which means that the greater the difference in surface area of wood fibers, the greater the difference in the amount of adhesive on individual fibers [Hwang and Hse 2005]. In addition, the absorption of large amounts of adhesive by dust can cause, if excessive dust is involved in the wood fiber mixture, insufficient gluing of larger filaments and the formation of clusters of overly fine wood particles. That is why it is of great importance to characterize wood fibers coming from fresh wood as well as from post-production materials used in the productions of wood-based panels. The knowledge of the size and quality of the fibers produced after production determines their suitability in the production process of lightweight boards. In the wood-based panels industry, a common measurement method for particle size distribution (PSD) is sieve analysis (AS). The reason for using this method derives from its low cost, simple procedure, and straightforward results. The size which is measured by SA [Sieve Analysis] is the second smallest dimension, i.e. the width of particle, that is why it is reasonable to use this method for spherical particles. Due to the anisotropic structure of wood, fine fibers and dust generated from the mechanical process are of irregular shape and its measurement only by SA can barely present their real characteristic [Ding et al. 2020]. On the other hand, for elongated fibres it is hard to fall through the sieves. In some studies, the image analyses (IS) method was suggested as an alternative for SA [Benthien et al. 2014]. In the presented research, an optical fibres analyzer was used as a tool for measuring PSD in post-production fibres.

In the production of low-density fiberboards (LDF), post-production materials are created at various stages of their processing. The number of post-production materials may vary depending on the type of boards produced and the method of their finishing (grinding, edges cutting, cutting to the required board size, milling). Based on the data collected during the production of various low-density fiberboards, it is estimated that approximately 14% of post-production waste is generated in the production of LDF boards in the form of different fibers fractions and dust. Of this, about 9% is produced by cutting the boards and milling to the finished product, and about 5% is produced by calibrating the boards on a grinder to the required thickness. There are at least two options for the use of post-production waste – combustion in a waste incineration plant and production of thermal energy in the form of process steam, and recycling of this raw material for the production of boards. However, from an ecological and economic point of view, it is advantageous to use the second solution. The production of very low density fiberboards (around 80kg/m^3), which so far has not been available commercially on the market, alone would reduce the consumption of full-value wood raw material compared to the standard product available on the market with a density of 110 kg/m^3, and thanks to the use of post-production waste, the product would be additionally more economical.

The purpose of this study was to produce a very low density insulation fiberboard with the use of post-production fibers, to characterize the post-production fibres, and to determine their maximum amount in a board without significant deterioration of the board parameters.

Materials and methods

Wood fibres

The low density thermal insulation boards were produced from pine fibres. To the based fibres obtained after defibration process various amounts of post-production materials (from 10% up to 60% in relation to dry fibres) were added. The post-production materials in the form of fibres of different fractions are formed during such mechanical processes as grinding, edges cutting, cutting to the required board size and milling of the finished product. To the post production material, fibres generated during the disqualification of the boards in a shredder are also taken into account.

Glue

As a binder commercial MDI glue was used with the following parameters:
Viscosity plate/cone Brookfield CAP 2000+ ISO 3219
SP01/150RPM/210C 600 - 800 mPas
SP01/150RPM/250C 460 - 520 mPas
SP01/150RPM/300C 300 - 360 mPas
- foaming max 200 %
- NCO group content 27 +/- 1% (EN ISO 14896)
- density 1.21-1.22 g/cm3 (EN ISO 2811-1)

Hydrophobization agent

Paraffin wax emulsion based on 100% synthetic waxes
Dry mass content 50 do 54%
Viscosity: 600-1100 mPa s (Brookfield)
Density at 20 °C: 0.95 g/cm^3

Lightweight insulations boards' manufacturing

The lightweight insulation fibreboards with nominal density of around 80 kg/m^3 (±20 kg/m^3), thickness of 60 and 240 mm and around 6% moisture content were produced. The production of lightweight insulation fibreboards was carried out in industrial conditions. The production process involved the first steps of debarking and chipping of pine wood. The chips were cooked in a digester at a temperate of 180 °C and pressure of around 9 bar and refined into wood fibres which then were mixed with a hydrophobization agent. The mixture of wet fibres and paraffine in the amount of 2% of dry mass were dried in a tube dryer at a temperature of 130-150 °C at the beginning of the dryer and 60-70 °C at the end of the dryer. MDI glue was applied in the amount of 7-8% on dry fibres and after that, the glued fibres were transported to the mat former before it was pressed to produce a continuous mat. The fibre mat was pressed using steaming press at a temperature of 150 °C. The amount of steam for 60mm boards was 60 kg/h for middle steaming boxes and 30 kg/h for the outer ones. For 240 mm boards the dosage of the steam was 55 kg/h for middle steaming boxes and 35 kg/h for the outer steaming boxes. The amount of applied steam is related to the capacity and speed of the production line. In the final processing stage, the boards were trimmed and cut to specified dimensions.

Post-production material in different amounts was automatically added to fresh fibers from the bin, where it is collected from the sanding, edge cutting, trimming to the required board dimensions and milling. Post-production material from the shredder was also fed directly into the fresh fibre bin after the refiner.

Methods

The fibers, used for the lightweight insulation board production, were measured using an optical fibre analyser – AWK Fiber Analyzer (Kamika Instruments). The measurement is based on the theory of geometric optics and involves the measurement of fibres in a parallel light beam (infrared radiation). The analysed wood fibres, moving in the air, weaken the luminous flux recorded by the photodiode. A measure of the magnitude of this weakening is the amplitude of the electrical signal formed by the electronic circuit. The pulse amplitude corresponds to the maximum particle size in spherical calibration. After sieve calibration according to the Elsieve method (Patent RP No. 205738), the collection of particles can be presented according to the traditional method of measuring on mechanical sieves. For every type of fibres three measurements were performed each on 50 000 fibres.

All the boards, produced during the tests, were measured in terms of their physicomechanical properties according to standardized methods defined in EN 13171. Additionally, the density profile was measured on EWS DENSE-LAB X. The laboratory density profile measuring system, based on X-ray technology, determines the density distribution over the sample thickness (perpendicular to the panel surface). The measurement was carried out on samples 50×50mm.

The following variants were tested (Table 1):

Table 1. Variants of the tests

Variants	Thickness of the board [mm]	Amount of post-production material from the bin [%]	Amount of post-production material from shredder [%]	Total amount of added post-production material to board [%]
1	60	0	0	0
2	60	10	0	10
3	60	20	0	20
4	60	30	0	30
5	60	40	0	40
6	60	40	10	50
7	60	50	10	60
8	240	0	0	0
9	240	20	0	20
10	240	40	0	40
11	240	60	0	60

Results and discussion

Due to the fact that wood fiber insulation materials are around 80% made of wood, it can be expected that the fibers preparation and their quality play an important role in the creation of the product with specific parameters. During the production of lightweight insulation board quality of the fibers was checked directly after their production on a refiner and after drying them in a flash dryer. Another point of sampling the fibers was the scale before gluing. At this point, depending on the process adjustments the fibers can be directly from the refiner or they can be a mixture with the fibers from different stages of the finished product processing. The appearance of the fibers after refining of wood chips can vary as the operating parameters and production conditions (e.g. size and moisture of the chips, refiner settings, wear of refiner discs) can change. Fig. 1 shows a typical distribution of the size of the fibers in the production of low density fiberboard after the refiner.

Fig. 1. The fibres distribution after refiner and before gluing

The proportion of the fibers fraction before the gluing process may also change depending on the number of fibers coming from the post-production material. Therefore, in these studies, particular attention was paid to how the share of post-production material can affect the insulating lightweight board parameters with a density of 80 kg/m^3 (±20 kg/m^3). In Fig. 2, the differences between post-production fibers were presented.

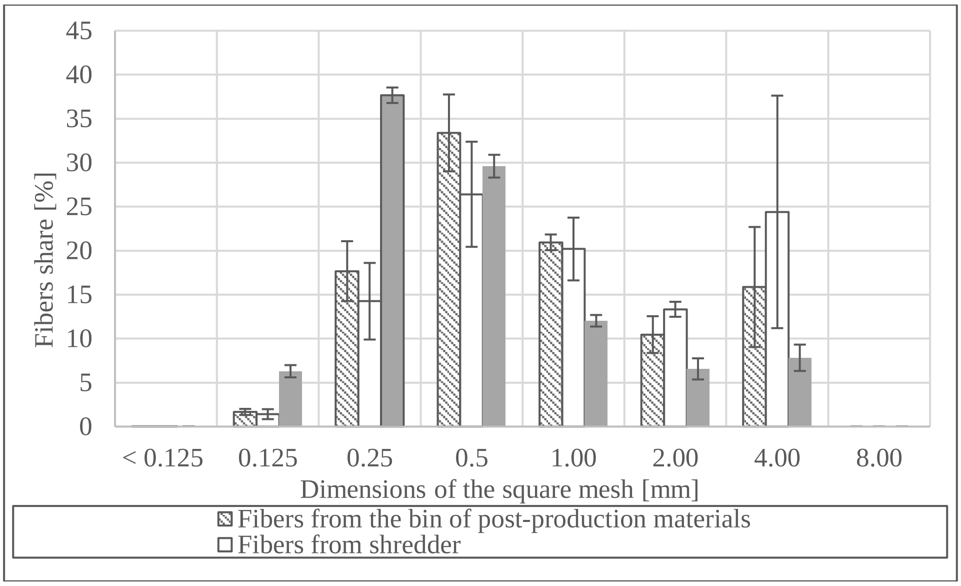

Fig. 2. The fibres distribution of post-production fibres

The finest fibers are formed in the process of grinding. While the thicker fibers are produced during the disqualification of the boards in the shredder, the size of these fibers depends largely on the type of board that is being disposed of at the moment. The density of the shredded boards can vary from 110 to 220 kg/m^3. That is why the share of the fibers above 4 mm in Fig. 2 varies from 10 to above 35%. Other fibers that make up the post-production material come from such production operations as edge cutting, cutting boards to the required size, and milling. Due to the fact that it was not possible to take separate samples of fibers from the above-mentioned operations, for analysis fibers samples were taken from the bin in which the fibers from the above mentioned operations together with fibers obtained from grinding are collected. The post-material is changing depending on what kind of processing of finish products was performed in the given moment. During the test production of 60 mm lightweight board up to 40%, post-material fibers were added only from the bin above 40% also partially fibers from the shredder. In the case of 240 mm boards, post-production material was only from the bin. Base fibers and additional post-production materials were analyzed in the laboratory. The results of the fibers fraction share for each variant (Table 2.) indicate significant differences only in the case of the fibers content above 4 mm and partially in the range of 0.5-1.0 mm.

Table 2. Analyses of the fibers fractions share for each variant

Variants	Thickness of the board [mm]	<0.125 mm	0.125 mm	0.25 mm	0.5 mm	1.0 mm	2.0 mm	4.0 mm	8.0 mm
1	60	0.00	1.38 (0.51)*	16.01 (3.29)	27.98 (1.92)	25.04 (2.10)	16.50 (1.50)	13.08 (2.15)	0.00
2	60	0.00	1.30 (0.45)	16.32 (1.74)	30.81 (4.34)	25.31 (3.60)	13.98 (1.31)	12.27 (3.93)	0.00
3	60	0.00	1.94 (0.27)	19.89 (1.51)	29.46 (1.13)	24.50 (0.82)	14.96 (2.28)	9.26 (0.80)	0.00
4	60	0.00	1.53 (0.27)	17.37 (2.16)	29.73 (0.72)	25.43 (0.85)	15.40 (0.40)	10.53 (2.32)	0.00
5	60	0.00	1.47 (0.10)	18.66 (1.58)	31.30 (1.80)	25.89 (5.09)	12.35 (3.40)	10.31 (1.81)	0.00
6	60	0.00	1.32 (0.58)	18.86 (4.09)	36.60 (3.51)	24.81 (1.25)	11.64 (1.42)	6.78 (1.63)	0.00
7	60	0.00	1.24 (0.25)	17.76 (2.03)	35.42 (1.15)	25.97 (2.37)	13.74 (1.44)	5.87 (2.26)	0.00
8	240	0.00	1.09 (0.14)	13.88 (1.14)	28.31 (1.45)	27.71 (0.85)	19.89 (3.38)	9.11 (3.05)	0.00
9	240	0.00	1.96 (0.30)	17.04 (2.18)	24.74 (2.60)	23.09 (1.93)	14.97 (3.32)	18.20 (4.09)	0.00
10	240	0.00	1.56 (0.13)	18.04 (0.62)	33.99 (1.37)	25.36 (2.34)	12.56 (0.97)	8.49 (4.09)	0.00
11	240	0.00	1.45 (0.19)	15.58 (1.11)	31.99 (0.55)	29.42 (0.58)	17.21 (1.11)	4.36 (1.46)	0.00

* standard deviations

Separately measured fibers from the bin of post-production fibers and from the shredder are presented in Table 3. As the fibers from the shredder are more coarse, the amount of this material in lightweight board was limited to 10% in two variants (6 and 7) of the study.

Table 3. Analyses of the fibres fractions share from the bin and shredder during the production test

Fibres sample	<0.125 mm	0.125 mm		0.5 mm	1.0 mm	2.0 mm	4.0 mm	8.0 mm
Post-production fibers from the bin	0.00	2.02 (0.31)*	19.63 (1.14)	34.68 (5.45)	22.09 (3.11)	9.57 (4.39)	12.00 (4.33)	0.00
Fibers after the shredder	0.00	0.82 (0.08)	9.25 (0.57)	21.08 (1.25)	17.21 (1.35)	13.42 (1.44)	38.21 (2.46)	0.00

* standard deviations

Table 4 shows the parameters of the lightweight insulation board. One of the most important parameters of insulating materials is the thermal conductivity (λ). The lower the λ value, the better the thermal insulation properties of the material. From the conducted test it can be pointed out that the lower thermal conductivity was achieved for variant 6 and the highest for variant 9. Very slight differences were observed for the 60 mm boards in the measured lambda. The best-known parameters affecting thermal conductivity are the thermal conductivity of the raw materials used, the pore structure of the insulating material, the fiber fineness – and orientation, the temperature, the behavior towards water and moisture as well as the density. In the wider density range of 100-800kg/m^3 for wood-based materials thermal conductivity increasing rather linearly with increasing density but decreases with decreasing particle size of the material [Sonderegger and Niemz 2009, 2012]. In the case of very low density materials and in a narrow range of density, as is shown in Fig. 3, connection between density and thermal conductivity is an e-function, and for the presented results it is very weak, even though the trend can be noticeable.

Table 4. The parameters of lightweight insulations board

Variant	Thermal conductivity λ 23/50 [W/mK]	Density [kg/m3]	Density profile max top of sample [kg/m^3]	Density profile max bottom of sample [kg/m^3]	Moisture [%]	Short term water absorption by partial immersion (24 h) [kg/m^2]	Water absorption 2h [%]	Compressive strength [kPa]	Tensile strength [kPa]
1	0.0371 (0.00044)*	94 (6)	122	110	6.2 (0.2)	0.40 (0.03)	84.40 (12.16)	58 (9.6)	17.7 (3.2)
2	0.0370 (0.00000)	88 (5)	117	92	6.2 (0.2)	0.38 (0.02)	90.60 (13.00)	53 (4.3)	14.2 (2.2)
3	0.0370 (0.00047)	88 (6)	114	101	6.4 (0.1)	0.44 (0.06)	89.62 (35.50)	58 (7.5)	17.6 (1.7)
4	0.0371 (0.00044)	91 (2)	117	98	6.5 (0.1)	0.40 (0.05)	66.30 (11.70)	58 (1.8)	15.8 (0.7)
5	0.0371 (0.00045)	89 (5)	105	91	6.2 (0.1)	0.48 (0.08)	95.95 (10.30)	52 (5.5)	16.0 (4.2)
6	0.0366 (0.00028)	89 (6)	107	94	6.8 (0.1)	0.39 (0.03)	54.65 (2.19)	48 (5.5)	15.0 (2.6)
7	0.0374 (0.00042)	91 (5)	109	98	6.5 (0.1)	0.41 (0.03)	90.60 (10.2)	57 (1.3)	17.5 (1.4)
8	0.0371 (0.00042)	102 (6)	132	121	5.6 (0.1)	0.61 (0.09)	70.44 (22.26)	54 (9.7)	13.2 (2.0)
9	0.0383 (0.00000)	96 (4)	130	125	5.6 (0.1)	0.70 (0.09)	58.80 (26.08)	67 (6.5)	17.2 (2.2)
10	0.0374 (0.00022)	95 (6)	146	149	5.5 (0.1)	0.69 (0.14)	68.20 (12.07)	61 (1.4)	16.7 (0.8)
11	0.0379 (0.00000)	97 (5)	140	148	5.7 (0.1)	0.56 (0.05)	48.50 (21.90)	66 (7.2)	17.7 (4.7)

* standard deviations

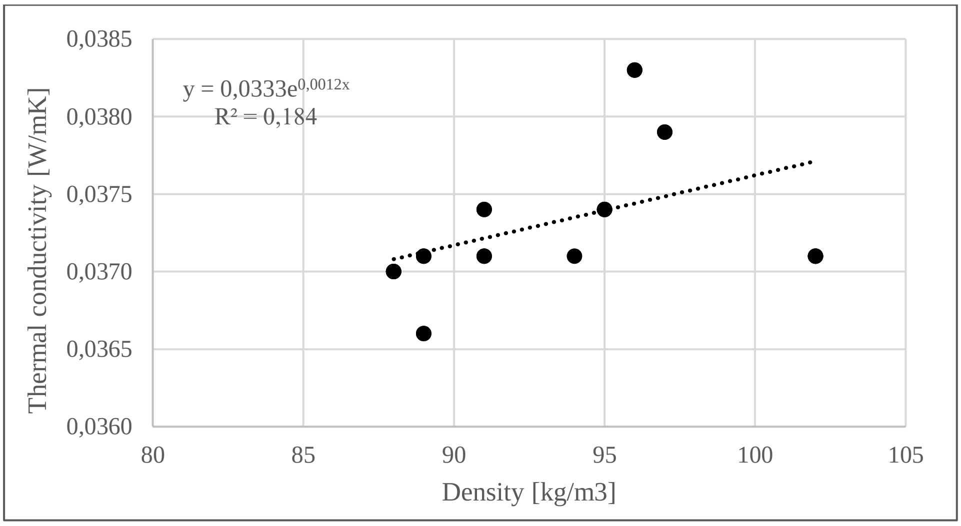

Fig. 3. Connection between density and thermal conductivity of a lightweight board

It means that besides the density of insulation fiberboard the structure of the material, the size of the fibers, and their shape itself play a crucial role. In the case of the presented results, a much better correlation is achieved between thermal conductivity and compressive strength of the boards. From Fig. 4 it can be seen that the higher the compressive strength, the worse the lambda of the board.

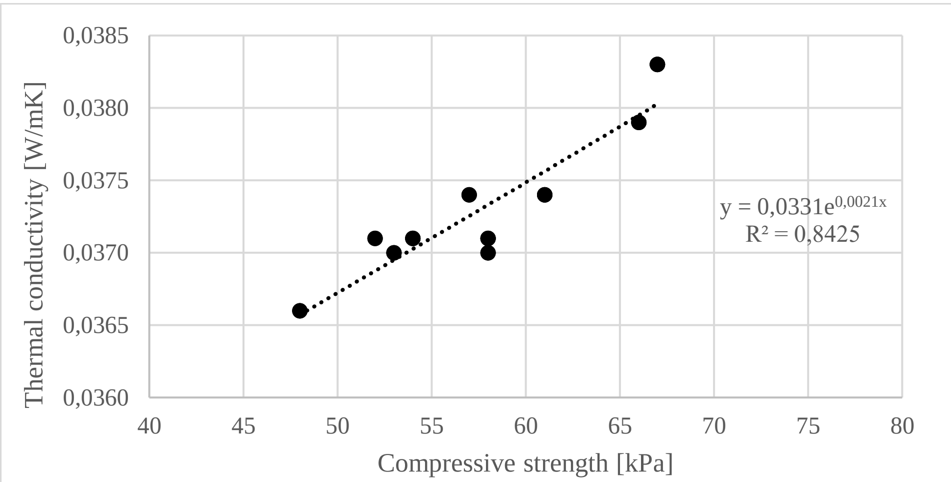

Fig. 4. Correlation between compressive strength and thermal conductivity of a lightweight board

The reason for such a good correlation compared to the correlation between thermal conductivity and board density may be that the compressive strength is more related to the board density profile and the fibers fraction in the board. When there is too much fraction between 2-4 mm and above 4 mm it can be noticed higher compressive strength but also higher thermal conductivity (variant 9). As it is shown in Fig. 5 and 6 density profiles were more homogeneous for 60 mm boards. For 240mm boards, the density close to the surfaces was much higher than the mean density for the sample what also affects the increase of thermal conductivity. This is especially noticeable for variant 11, in which, despite the greater number of fine fibers and the low density of the board, the thermal conductivity was quite high 0.0379 W/mK. The vertical density profile of low-density fiberboard is created from a combination of actions that occur in a pre-press during the consolidation of fiber mat and continues to develop after reaching the final position in the steaming press The interaction between heat transfer, moisture and pressure in the fiber mat during hot pressing decides what kind of density profile is formed. The geometry of the fibers that make up the mat also plays an important role in the formation of the density profile, as it significantly influences the permeability of the mat and the resulting vapor pressure gradient across the thickness of the mat, which determines the speed of heat transfer during pressing [Rebolledo et al. 2018; Euring et al. 2016; Wong et al. 2000].

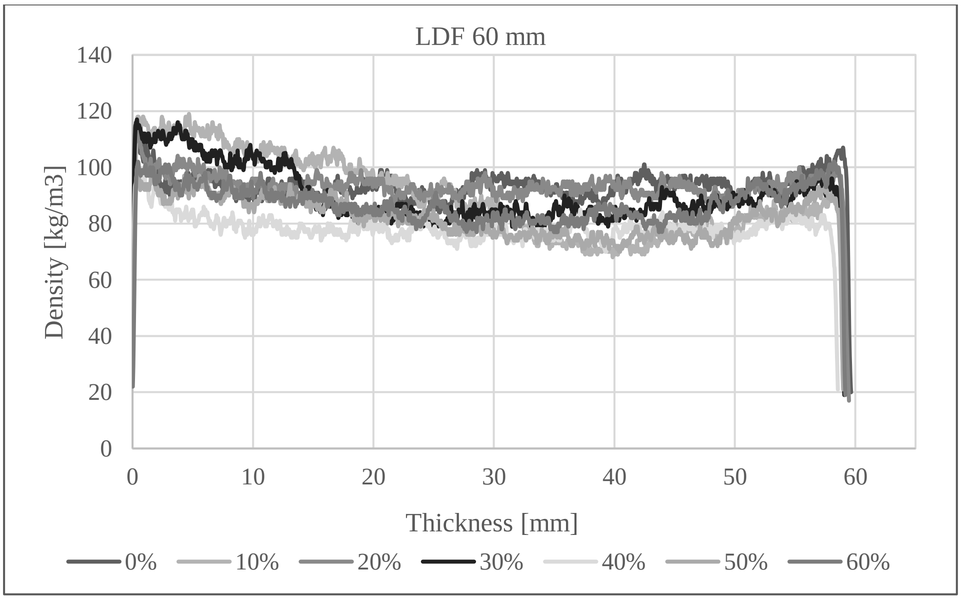

Fig 5. Density profile of 60mm low density fiberboard with different amount of post-production fibres.

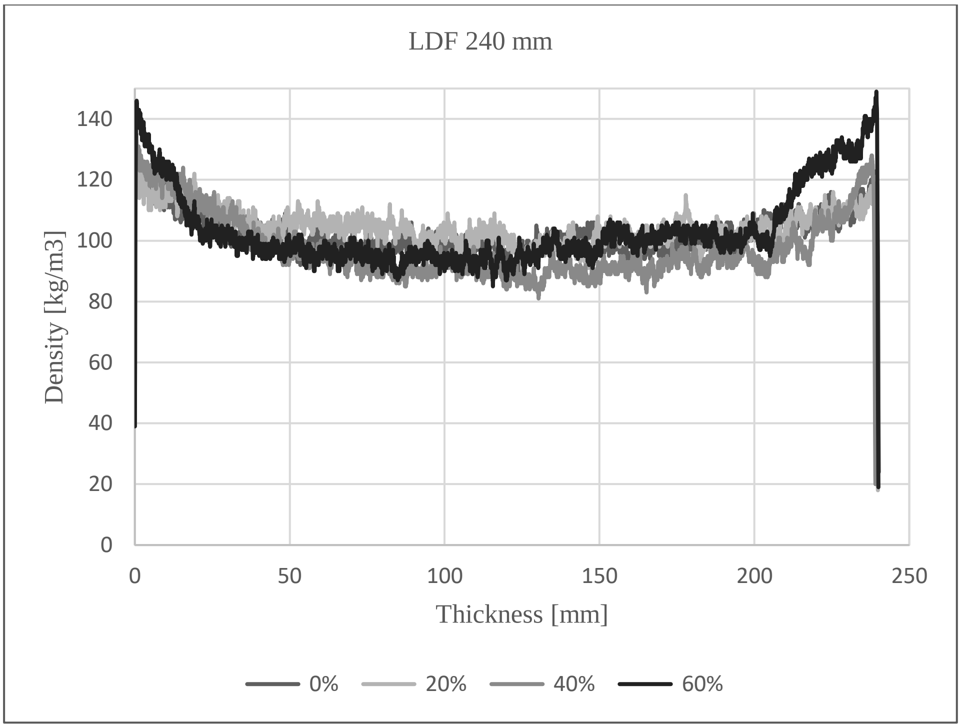

Fig 6. Density profile of 240mm low density fibreboard with different amount of post-production fibres.

In terms of short term water absorption (WS), measured by partial immersion of the samples in water and expressed in units of kg/m^2, no direct influence of the amount of post-production material added on this parameter was found. Mean WS for 60mm lightweight board was 0,41 kg/m^2 and for 240 mm board 0.64 kg/m^2. The difference is connected more with the methodology of the measurement and some proven influence of the board thickness on this parameter. Some differences are noticeable in terms of water adsorption after the sample is completely immersed in water for 2 hours even the same amount of hydrophobization agent was added for all produced boards. These differences may be related to the structure of the board and the proportion between the fiber fractions in the board composition. However, the results are not conclusive.

In the case of tensile strength perpendicular to the surface, no significant differences were noticed between the studied variants.

Conclusions

1) During the production test, not direct and clear influence of the amount of added post-production material to lightweight fiberboard parameters was found. The reason for this is too small differences, especially in the case of 60 mm boards, in the fibers fraction distributions between individual variants. For 240 mm boards, the differences in fiber fractions distribution are bigger, especially in terms of fibers between 0.5-1.0 mm and above 4mm. The increased amount of 4 mm fibers caused the increase of thermal conductivity and compressive strength of lightweight board.
2) Post-production fibers vary depending on the production process from which they come. The finest fibers are obtained by grinding the board, coarser fibers are created when cutting and milling the finished product, but also when shredding boards that do not meet the requirements.
3) For very low density fiberboards it is essential, that added post-production fibers are more alike to the fibers produced on refiner in adjusted fibers size distribution, this means the elimination of the finest and the coarsest fibers. One way to achieve this goal would be to eliminate the grinding process which creates very fine fibers. Additionally, as it is well known from the literature, this would help to eliminate the absorption of large amounts of adhesive by dust and very fine fibers which can cause, if excessive dust is involved in the wood fiber mixture, insufficient gluing of larger fibers, and the formation of clusters of overly fine wood particles.
4) The addition of coarse fibers from the shredding of boards not meeting the requirements, in the case of very low density boards, should be avoided or minimized because too many coarse fibers increase thermal conductivity.
5) The parameters of the lightweight board which are the most influenced by the dimensions of the fibers used, are mainly thermal conductivity and compressive strength. However, additional research would be needed on how the geometry of the fiber affects water sorption.
6) At the time of conducted research, fibers were not measured online during production, as currently there is no such measuring system at the production line available, therefore it is not always possible to show real differences in the fiber fraction share.
7) The fibers measurement system should be more investigated, especially when measuring very fine fibers.

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List of standards

EN 823:2013-05 Thermal insulating products for building applications — Determination of thickness
EN 826:2013-05 Thermal insulating products for building applications — Determination of compression behaviour
EN 1602:2013-05 Thermal insulating products for building applications — Determination of the apparent density
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