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ATTEMPTS AT APPLICATION OF POLYETHYLENE-COATED WASTE PAPER AS A RAW MATERIAL IN THE INSULATION BOARDS PRODUCTION

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Abstract

This study evaluates the usage of polyethylene-coated waste paper as a raw material for production of insulation boards. As part of the research, single-layer boards were made of waste paper covered on one side with polyethylene. The produced boards varied in density: 203, 311 and 397 kg/m^3. Thermal conductivity, volumetric heat capacity and temperature conductivity were evaluated. The MOR values of panels covered with double-sided hardboard panels were also determined. Boards obtained from waste paper covered on one side with polyethylene were characterized by thermal properties similar to those of insulating boards or straw boards (thermal conductivity: 0.077 ÷ 0.122 W/mK, volumetric heat capacity: $0.425 \cdot 10^6 \div 0.692 \cdot 10^6$ J/m^{3}K, temperature conductivity: $0.180 \cdot 10^{-6} \div 0.203 \cdot 10^{-6}$ m^2/s. After double-sided sealing with hardboards, boards can be used as insulating and structural material (MOR: 39.1 ÷ 92.2 N/mm^2).

Key words: *insulation boards, polyethylene coated waste paper, thermal properties, polyethylene*

INTRODUCTION

For many years, research has been conducted on the possibilities of using various types of post-consumer materials in the technology of wood-based panels (Nicewicz i in. 1997, Borysiuk i in. 2004, Pawlicki i in. 2005, Borysiuk i in. 2006, Müller i in. 2012). Particular attention in this respect is given to materials with limited application in other areas of life, and even those that are often useless waste. Such materials can undoubtedly include waste from multi-material packaging (bags, pouches, boxes for liquid food products). In their case, there are difficulties in separating individual raw materials: paper, aluminum or polyethylene. For the majority of multi-material packaging, recycling of post-consumer waste is not justified economically, technically and ecologically. Thermal recycling methods leading to energy recovery are often used in this field. It should be noted, however, that in general it is not possible to recover all the energy invested in the production of a given product. In addition, they often contain harmful substances, which combustion in itself is nuisance to the environment. According to industry data (ACE- The Alliance for Beverage Cartons and the Environment), in 2016 in the European Union, a total of 47% of beverage cartons were recycled in over 20 paper mills. This percentage

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corresponds to approximately 430000 tons of cardboard boxes. However, the total recovery rate including recycling and energy recovery was nearly 76% (https://www.tetrapak.com).

Shredded multi-material waste can be used to produce boards in chipboard technology. Tectan board is a chipboard-like material made from beverage cartons, both the scraps from production and used cartons. The drink cartons consist of various layers of paperboard, polyethylene and aluminium. In the production process of the board, the polyethylene melts and acts like a glue to keep the material together (https://materia.nl/material/tectan-board/). Another example of the possibility of recycling multi-material packaging is PolyAl roofing sheets. These are covering materials, similarly to Tectan, made of compressed multi-material waste with aluminum layer on one side (http://saahaszerowaste.com). Polyethylene coated paper can also be included in multi-material packaging. Due to the presence of plastic on the surface, this product cannot be recycled to paper. Its combustion may take place only under certain conditions.

This study presents the possibilities of re-using polyethylene coated paper as a raw material for the production of insulation boards. The big advantage of this material is in this case polyethylene, which as a thermoplastic, can be a board-binder. It is also important that this type of solution does not generate any burdens for the natural environment.

MATERIAL AND METHODS

The post-production waste paper with one side covered with polyethylene was used for the research. Paper weight with polyethylene layer was 100 g/m2. The material was in the form of long and narrow bands (Ryc. 1). During the tests, three variants of insulating boards with a thickness of 18 mm were produced, varying in terms of density: 200 kg/m^3, 300 kg/m^3 i 400 kg/m^3. Mattress were hand-formed. For the press cycle applied following settings: maximum unit pressure 1.5 MPa, pressing temperature 200°C, pressing time 15 min. The pressing time was adjusted to let temperature inside the plate exceeded 110°C (temperature at which the polyethylene begins to plasticize). The role of the binder in the plates was met by polyethylene applied on paper. After hot-press, the boards were fixed by cooling under pressure.

Ryc. 1. Paper strips coated on one side with polyethylene used in the research.

The produced panels were subjected to air conditioning in laboratory conditions for 24 hours. The following properties were determined for obtained panels:

- thermal conductivity,
- volumetric heat capacity,
- temperature conductivity.

The research was carried out using the ISOMET of Applied Precision. In the further stage of testing, boards were strengthen on both sides with 3 mm thick hardboards. For gluing components an urea-formaldehyde based resin was used. Glue recipe:

- 100 parts Silekol S-1 urea-formaldehyde resin,
- 25 parts filler - rye flour,
- 25 parts H_2O,
- 10 parts hardener - 10% aqueous solution of NH_4Cl.

The following gluing parameters were applied: glue application - 200 g/m^2 pressing temperature - 120°C; unit pressure -1.6 N/mm^2; pressing time - 5 min. During the pressing were used spacers, to prevent compression of the inner layer. For bonded boards, the bending strength was determined in accordance with the EN 310:1994 standard.

RESULTS AND DISCUSSION

The results of testing thermal properties of insulation boards are presented in Tables 1, 2 and 3. Table 4 displays the comparative values of thermal conductivity of selected materials.

Table 1. Thermal conductivity values of the insulating panels produced.

Density	Thermal conductivity			Standard deviation (SD)	Coefficient of variation (CV)
	min.	max.	mean		
[kg/m^3]	[W/mK]				[%]
203	0.069	0.089	0.077	0.008	10
311	0.092	0.105	0.097	0.005	5
397	0.107	0.144	0.122	0.012	10

Table 2. Volumetric values of heat capacity of the produced insulation boards.

Density	Volumetric heat capacity			Standard deviation (SD)	Coefficient of variation (CV)
	min.	max.	mean		
[kg/m^3]	[J/m^{3}K] x10^6				[%]
203	0.299	0.583	0.425	0.105	25
311	0.416	0.535	0.480	0.044	9
397	0.546	0.978	0.692	0.148	21

Table 3. Comparison of temperature conductivity values of the insulating panels produced.

Density	Temperature conductivity			Standard deviation (SD)	Coefficient of variation (CV)
	min.	max.	mean		
[kg/m^3]	[m^2/s] x10^{-6}				[%]
203	0.153	0.239	0.186	0.031	17
311	0.176	0.225	0.203	0.019	9
397	0.147	0.195	0.180	0.018	10

Table 4. Thermal conductivity values of selected materials (based on ISO 6946:2017)

Material	Density	Thermal conductivity
	[kg/m^3]	[W/mK]
Pine (*Picea*) (cross-cut)	550	0.16
Oak (*Quercus*) (cross-cut)	800	0.22
Insulating board	300	0.06
Strawboard	300	0.08
Styrofoam	10 ÷ 40	0.045 ÷ 0.040
Mineral wool board	40 ÷ 160	0.045 ÷ 0.042

The main parameter determining the possibility of using the panels as an insulating material is their thermal conductivity coefficient (λ). It determines the heat transfer capacity of a given material. The lower it is, the better the insulation. The obtained boards were characterized, depending on the density, by thermal conductivity at the level of 0.077 ÷ 0.122 W/mK (Tab.1). The recorded values of thermal conductivity are similar to those of insulation materials such as insulating boards or strawboards (table 4). In this respect, it is also worth noting that according to EN 13986:2004, the thermal conductivity of fiberboard with a density of 250 kg/m3 should be λ = 0.05 W/(mK) and for boards with a density of 400 kg/m3 λ = 0.07 W/(mK). However, the ISO 6946:2017 standard for fibreboards with the density of 300 kg/m3 indicates the value of heat transfer coefficient λ = 0.06 W/(mK). The thermal conductivity of the tested panels decreases as the density of the panels lowers, which is related to the increase in the content of free space filled with air. It is worth adding here, that the increase in the thermal conductivity of the tested panels, along with the increase in density, is approximately linear in nature, and the differences noted are statistically significant for the 95% confidence level.

Considering the volumetric heat capacity of the tested panels, it can be generally stated that, similarly as in the case of thermal conductivity, it increases with the density increase and is in the range of $0.425 \cdot 10^6$ – $0.692 \cdot 10^6$ J/m^{3}K. In general, heat capacity is the amount of heat needed to raise the material temperature by one degree. The increase in thermal capacity along with the increase in density is related to the loss of free-air-spaces. The amount of "solid" material in the board of higher density is naturally larger, and requires more energy to heat the material, according to EN 12524:2000, not less than 1700 J/kgK. In general, heat capacity (c) is calculated from the formula:

$$c = C/\rho \ [\mathrm{J/kg \times K}]$$

C – volumentric heat capaicty [J/m^{3}K],
ρ – density of the material [kg/m^3].

The average thermal capacity for plates produced under individual variants ranged from 1743 - 2094 J/kgK. It is worth of highlighting, that the differences noted in the research are statistically significant only in relation to panels with a density of 397 kg/m^3 (for a confidence level of 95%).

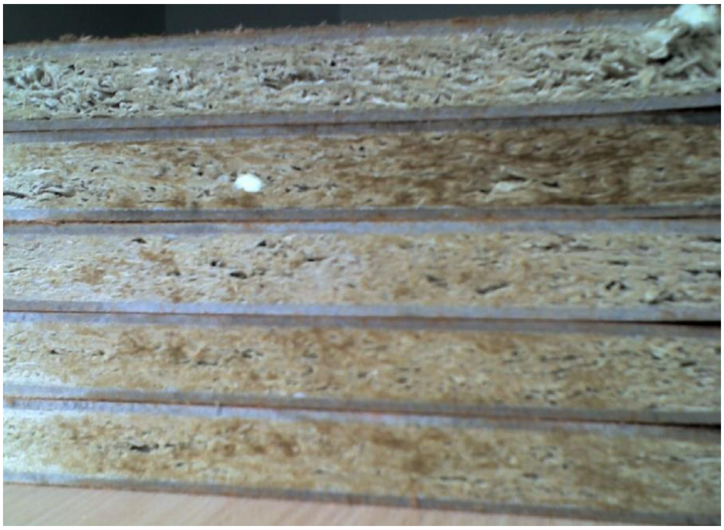
Unlikely to thermal conductivity and volumetric heat capacity, the temperature conductivity did not show a clear upward trend due to increase of boards density. Values for this parameter ranged from $0.180 \cdot 10^{-6}$ to $0.2 \cdot 10^{-6}$ m^2/s. Differences recorded for temperature conductivity were visible, however statistically insignificant. This type of conductivity is essential as materials with low conductivity give the impression of being "warm". That concerns wood, which temperature is $0.153 \cdot 10^{-6}$ ÷ $0.111 \cdot 10^{-6}$ m^2/s (for density 450 ÷ 700 kg/m^3) (Krzysik 1974).

The results of the bending strength test of the insulated boards are presented in Table 5.

Table 5. Comparison of bending strength values of the insulated boards

Density	MOR			Standard deviation (SD)	Coefficient of variation (CV)
	min.	max.	mean		
[kg/m³]	[N/mm²]				[%]
203	37.0	41.0	39.1	2.5	6
311	57.0	76.0	63.8	5.5	9
397	77.0	109.0	92.2	10.4	11

The uncoated insulation boards were characterized by low MOR values not exceeding 2 N/mm^2 (for panels with a density of 397 kg/m^3). It is worth noting, that according to the EN 622-4:2009 norm, insulating boards with density in the range of 230 kg/m^3 – 400 kg/m^3 should have MOR values above 0.8 N/mm^2. Double-sided coating of tested boards with a hardboard (Ryc. 2) allowed to obtain MOR values in the range of 39.1 - 92.2 N/mm^2 (Table 5). Boards manufactured in this way can therefore be used as an insulating and structural material.



Ryc. 2. Double-sided coated of tested boards with hardboard.

CONCLUSION

The insulation boards made of polyethylene coated paper were characterized by similar thermal properties to insulating materials such as insulating boards or strawboards. The boards can also be included in materials that give the impression of "warm" what creates the possibility of using them as a warming material. Double-sided sealing with hard fiberboards allows using the boards as insulating and structural material.

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