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Textile Waste from Woollen Yarn Production as Raw Materials for Thermal Insulation Products

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Abstract
In the current research, waste from woollen yarn production was analysed. Woollen yarn waste as raw material was used for the production of soft thermal insulation mats. Two types of mats were produced in a textile plant: thermally untreated and thermally treated. Properties such as the fibre composition, structure, and thermal conductivity of the thermally untreated and thermally treated mats were studied. During the composition analysis of the woollen yarn waste, the quantity of long, medium length, and short fibres was determined. The content of fats, salts, and other organic and synthetic impurities was investigated. The micro and macrostructures and contact zones between the fibres and the binding material were analysed. The dependences of the thermal conductivity on the density of the thermally untreated and thermally treated composites were obtained.

Keywords
textile waste, sheep wool, polylactide fibres, thermal insulation, thermal conductivity.

1. Introduction

The increasing environmental requirements are forcing the search for efficient waste management, usually recycling, reuse, or utilisation. The textile industry generates large amounts of waste. About 9.35 million tons of textile waste are collected in the European Union and more than 17 million tons in the United States each year [1, 2]. Researchers point out that part of the textile waste from individual consumers remains uncollected, hence measures are being sought to make the collection of textile waste more efficient by 2025 [3]. According to American researchers, 66% of the waste collected was sent to landfills, 19% combusted with energy recovery, and only 15% was recycled [4]. In most cases, the recycling of textile waste depends on its type and source. One author stated that most of the fibrous waste is composed of natural and synthetic polymeric materials. Therefore, all waste must be collected and sorted prior to recycling. After sorting, various mechanical, dissolving, melting, depolymeriation, and other processing operations can be used. Subsequent reuse depends on the specific product being developed [5].

In scientific research, the recycling of textile waste is associated with various fields: it is used as a fuel, as well as in various building composites, yarns, geotextiles, filtration membranes, fertilizer, etc.

In research work [6], the hydrothermal pretreatment of cotton textile waste was performed at 240 °C–340 °C to obtain bio-crude oil and biochar. The results obtained demonstrate the feasibility of converting waste cotton textiles into high-quality biofuels or even electrocatalytic carbon materials via hydrothermal treatment.

Another study [7] aimed to test both the mechanical and durability properties of short random textile waste fiber as a potential reinforcement for cement composites oriented to building components with low structural responsibility (e.g. aesthetic facade panels, cladding). Recycled waste consisted of cotton and polyester fibers from the clothing and textile waste industries. Different mixtures containing 6-10% textile waste were examined. The results showed that the compressive strength and flexural stiffness of the textile waste composite were on average 12% higher compared to the reference sample. Reference and textile waste composites were also subjected to accelerated aging. The results of textile waste composites showed better mechanical characteristics (by at least 10%) compared to reference samples.

In research [8] a complete process is presented to develop a novel thermal insulation material using synthetic material cutting waste. Thermal insulation panels were developed using compression moulding. A sample matrix of panels with different proportions of nylon and polyurethane was subjected to thermal conductivity testing.

A Pakistani and Czech research group [9] used spinning waste and converted it into a value-added product. Different blends of fiber were reclaimed from yarn waste and rags/fabric clippers. These fibers were converted into open end yarn. The researchers stated that these recycled yarns can be used to manufacture higher quality textile products such as denim, chino cloth for trousers, and towels.

Researchers [10] investigated whether it is possible to utilise cotton textile waste as a source of cellulose for the fabrication of cellulose membranes. The effect of the casting thickness and cellulose concentration on the performance of the membranes prepared was studied. The results showed that very hydrophilic ultrafiltration membranes with attractive permeability and retention properties can be made from textile waste. 1 m^2 of cotton bed linen is enough to produce approximately 20 m^2 of cellulose membrane.

In the review article [11], researchers studied a total of 49 researches to formulate the application-based characterisation of textile waste fibers in a comprehensive way to determine their suitability as a composite material in sustainable construction and geotechnical practices. The authors concluded that textile waste possesses enormous potential for valorisation in the fields of construction and geotechnical engineering, and this is a major area in which the circular textile economy can flourish.

Researchers in [12] stated that by using hydrolysis with superheated water, it is possible to convert wool waste into amendment fertilisers. The fertilizers obtained may be used as nitrogen fertilisers in organic agriculture or as biostimulants.

Products made from textile waste or only part thereof have very different applications in the construction industry. Massive products can be used for thermal-structural and acoustical-structural purposes, or lightweight products for thermal or sound insulation purposes, or for both [13-16]. In the production of massive products, usually with a cementitious binder, it is important to obtain not only good thermal and sound insulation characteristics but also good strength characteristics. Furthermore, in such products, textile materials provide the reinforcing function of the composite, reduce shrinkage, and increase durability [7].

Valverde et al., [17] studied the preparation and characterisation of new materials made of textile waste derived from polyester and polyurethane by thermoforming. The thermoforming temperature was set at 190°C to ensure that the degradation temperature of the more unstable material, polyurethane, was not reached. The pressure time was 15 min. The authors stated that the thermal conductivity values of the newly developed product were similar to those of other commercial insulation materials.

Patnaik et al., [18] studied thermal and sound insulation samples developed from waste wool and recycled polyester fibers for building industry applications. The density of the samples ranged from 58.8 to 66.7 kg/m^3. All samples were made by needle-punching technology. All the samples developed showed good thermal insulation, acoustic absorption, moisture absorption, and fire resistance properties.

In another study, the sheep wool of crossed breeds was used [19]. The fibers were combed, and short fibers were removed as waste. The waste fibers were spun to produce coarse spun-yarns of almost identical diameter. The yarns were then used as weft yarn with a weft density of 18/cm to produce plain wool fabrics. For all samples, the warp yarns were wool yarns of 520/6 ± 1.5 tex with a warp density of 12/cm. All plain woolen fabrics showed good sound absorption and thermal insulation properties.

In most cases, the production technologies and compositions of the products supplied to the market are not disclosed. According to the assortment of products suggested, we can decide whether they are produced using different production technologies. The product types suggested in the market are very wide: rolls, felts, panels, loose fill, and blowing insulation.

The aim of this paper was the development of thermal insulation materials based on woollen yarn waste and the study of their production technology and properties. This paper describes the preparation of thermal insulation materials from woollen yarn waste using carding technology. Wool waste materials can be used in the building sector as thermal insulation material for the insulation of various non-load-bearing enclosures.

2. Materials and test methods

2.1. Materials and their preparation

For the experiments, waste from the production of woollen yarn was used. Raw material was received from JSC Danspin, Lithuania. Unspun woollen fibres formed during various wool processing operations up to the spinning stage were used for the tests. According to [20], waste from the spinning of textile fibers accounts for about 11 percent. In addition, defibred woollen yarn waste was used. Three types of compositions were carded from woollen yarn waste in a carding machine. All compositions are presented in Table 1. The compositions presented were selected based on the results of previous studies [21, 21].

Polylactide (PLA) as the binding material was supplied by MAXModel s.a.s, France. The main characteristics of the PLA fibres were as follows: 4.4 dtex, length - 51 mm, and melting temperature - 130°C. PLA and wool fibres were mixed using an internal mixer. During the carding process, the mixed fibres were combed in the same direction to create composite webs. The resulting web of aligned fibres was then cross laid into several layers that overlapped. The degree of overlap depended on the desired density of the product. Part of the web produced was thermally untreated, and the other part of the prepared web was conveyed through an oven to allow the PLA to melt. The web was then hardened in an oven for 3 minutes at a temperature of 160°C. The thickness and density of the thermally treated composite were controlled by the two drums on which the material was conveyed. After compression between the drums, the material was transported out of the oven and naturally cooled at ambient air temperature to provide dimensional stability to the product. The thermally treated composite was cut to the required length and width.

Mixture No.	Weight percentage of input components, %		
	Waste from woollen yarn production	PLA	Waste from defibered woollen yarn
1	100	-	-
2	87	13	-
3	74	11	15

Table 1. Compositions of mixtures for the production of thermal insulation

2.2. Determination of woollen yarn waste composition

The composition of the woollen yarn waste was determined by two methods. The length of fibres and their number in the raw material, as well as the composition of non-fibrous matter and the content of different fibres, were determined. In the first case, by combing the raw material by two hand carding combs, three fractions of fibres were obtained, and their mass was fixed. For that purpose, 5 samples of 40g each were taken from different parts of the wool package. In the second case, the amounts of non-fibrous matter were determined by extraction on Soxhlet apparatus according to ISO 1833-1 [23] and the different fibre content according to ISO 1833-4 [24], ISO 1833-7 [25] and ISO 1833-11 [26] standards.

2.3. Thermal conductivity measurement

Thermal conductivity measurements were carried out on specimens of 300 × 300 × 50 mm dimensions at a mean temperature of 10°C according to the requirements of EN 12667 [27] and EN ISO 8301 [28] using a device of symmetric configuration with horizontal heat flow meters and protection of the lateral surfaces of the specimens - FOX 304 (Laser Comp., USA). The direction of heat flow was upward, and the temperature difference between the cold and hot plates was 20°C. The specimens were preliminarily brought to balanced hygroscopic moisture at a temperature of 23 ±2°C and relative humidity of 50 ± 5%.

2.4. Analysis of the composite structure

To analyse the structure of the composites, specimens of 40×40×40 mm were prepared. The specimens were inspected by a Zeiss EVO-50 EP scanning electron microscope (SEM). Additionally, the samples were coated with carbon prior to SEM measurement. The analysis was performed using thevariable pressure mode at an accelerating voltage of 20 keV and working distance of 10 mm to 15 mm.

2.5. Methods of processing the experimental data

For processing of the experimental data and evaluation of their reliability, mathematical-statistical methods, along with the programme 'STATISTICA' were used [29].

Mathematical-statistical analysis of the experimental data led to a description of the relation between density and thermal conductivity λ_{10}, W/(m·K) by regression equation (1):

$$\overline{\lambda}_{10^\circ C} = b_0 + b_1 \cdot \rho + \frac{b_2}{\rho}, \qquad (1)$$

where $\overline{\lambda}_{10^\circ C}$ is the thermal conductivity value at the mean measurement temperature - 10°C in W/(m K); ρ is the density of the specimen in kg/m^3; and b_0, b_1, b_2 are constant coefficients calculated according to the experimental data using the least-squares method [30].

The variation in the parameter examined $\overline{\lambda}_{10^\circ C}$ on the controlled input factor ρ is presented as the coefficient of determination R^2 (that is, the square of the correlation coefficient R).

The standard deviation S_r (a measure of the amount of variation or dispersion of a set of experimental values) was determined according to equation (2) [30]:

$$S_r = \sqrt{\frac{\sum_{i=1}^{i=n}(\lambda_{xi} - \overline{\lambda}_{xi})^2}{n-m}}, \qquad (2)$$

where λ_{xi} and $\overline{\lambda}_{xi}$ are the actual and *i*-value of the resulting characteristic calculated by Eq. (1); n is the number of test results, and m is the number of estimated constant parameters.

3. Results and discussion

Test results of the combed waste specimens are presented in Table 2.

As seen in Table 2, the largest amount is those fibers with a length of more than 30 mm. The amount of average length fibres and short fibres with dust is very similar in the waste. It should be noted that short fibres and dust are not suitable for the production of composite materials because small particles drop out between the combs and rollers during technological operations. The total amount of long and medium fibres is approximately 74%, which is suitable as a raw material for the production of thermal insulation products. During visual inspection of the combed fibres, it was found that the amount of short fibres and dust by volume is about 2.5 times smaller than that of the average length fibres at the same material weight. It means that small particles are heavier and denser.

In a later stage, all specimens were grouped into two types: the first was suitable for the production of thermal insulation with a fibre length ≥10 mm, and the second unsuitable for the production of thermal insulation with a fibre length <10 mm. In Tables 3 and 4 test results of the determination of the non-fibrous matter and fibre content in long and average length fibres are presented. First, non-fibrous matter – oils, fats, waxes, salts, etc. was removed from the fibres. The test results showed that the content of non-fibrous matter in the fibres is about 3.9%. After removal of the non-fibrous

Amount, mass %		
Long fibres (>30 mm)	**Average fibres (10÷30 mm)**	**Short fibres and dusts (< 10 mm)**
47.7	26.3	26.0

Table 2. Composition of woollen yarn waste

No. of specimen	Non-fibrous matter, mass %	
	Quantity of oils, fats, and waxes	**Salts and etc.**
1	1.1	2.7
2	1.0	2.8
Mean value	**1.1**	**2.8**

Table 3. Quantity of non-fibrous matter in long and medium length fibres

No. of specimen	Fibres, mass %			
	Sheep wool fibres	**Polyamide**	**Wood resins and polyester fibres**	**Cellulose fibres (grass, wood pieces and etc.)**
1	94.7	0.5	0.1	0.9
2	95.3	0.4	0.1	0.4
Mean value	**95.0**	**0.4**	**0.1**	**0.6**

Table 4. Quantity of fibrous matter in long and medium length fibres

No. of specimen	Fibre content, mass %		
	Sheep wool fibres	**Wood resins, polyester fibres, and polyamide fibres**	**Cellulose fibres (grass, wood pieces and etc.)**
1	91.2	1.4	7.4
2	91.6	1.2	7.2
3	93.0	0.6	6.4
Mean value	**91.9**	**1.1**	**7.0**

Table 5. Quantity of fibrous matter in short length fibres

matter, separate fibres were identified. It was found that the part of pure sheeps wool amounted to ~ 95.0%, and the other fibres together were ~1.1%.

In the initial stage before sheep wool treatment, as was stated by Zach et al. [31], in sheep wool raw material about 10% of fats, 10% of sweats, and 5% of impurities are found. Our test results show that not all by-products are removed during the washing process of raw sheep wool. A large amount of by-product can worsen the contact zones between sheep wool and polylactide fibres.

The results of the fibrous matter determination test for short fibres are presented in Table 5. While the fraction of short fibres consists of very small particles, non-fibrous matter was not removed. The investigations showed that the pure sheep wool fibres in the short length waste amount to about 3.1% less than in the long length waste, the quantity of other polymeric fibres is about 0.6% larger, and the that of cellulose fibres is about 6.4% larger than in the long length waste. Based on the test results, we can conclude that in the production of yarns during different processing operations, sheep wool fibres do not tend to break and crumble, and hence pure sheep wool fibres in short length waste decrease. The difference in the waste of other polymeric fibres is very small and may be influenced by the inhomogeneity of the materials. A large quantity of cellulose fibres in short length waste is due to a number of circumstances. First, cellulose fibres are crumblier than sheep wool and break during different processing operations. Second, at the initial stage, the length of cellulose fibres is less than that of sheep wool fibres, and short cellulose fibres are entangled between longer sheep wool fibres.

3.1. Thermal conductivity

The main characteristics of thermal insulating materials are thermal conductivity and thermal resistance. Without the thickness of the materials, it is impossible to describe their thermal resistance . If a thermal conductivity indicator is used, the heat transfer intensity of different materials can be compared. A lower thermal conductivity shows a lower thermal transmittance of the material.

Before starting thermal conductivity studies of the composite, the thermal conductivity of combed woollen yarn waste and PLA fibres was investigated separately (Fig. 1). The thermal conductivity of the woollen yarn waste was determined in the density range of 20.7 kg/m^3 to 55.2 kg/m^3, respectively; the thermal conductivity in this density range ranged from about 0.0421 W/(m·K) to 0.0330 W/(m·K). Thermal conductivity studies showed that with an increase in the density of the specimens of about 2.7 times, a decrease in thermal conductivity of about 30.3% is observed. Since PLA fibres were used as a binder to bind the fibres, it is important to investigate the thermal conductivity of the binder as well. The thermal conductivity coefficient of PLA was determined in the density range of approximately 20.2 kg/m^3 to 58.1 kg/m^3, respectively; the thermal conductivity in this density range ranged from approximately 0.0404 W/(m·K) to 0.0331 W/(m·K). Studies of PLA fibres

Number of regression equation	Number of tests (estimations)	Values of constant coefficients			S_r, W/(m·K)	$R^2_{\lambda_{10}}$·φ
		b_0	b_1	b_2		
3	18	0.0223	0.000069	0.3813	0.000168	0.998
4	24	0.0258	0.000041	0.2818	0.000170	0.995

Table 6. Results of the statistical processing of the thermal conductivity of PLA fibres and woollen yarn waste

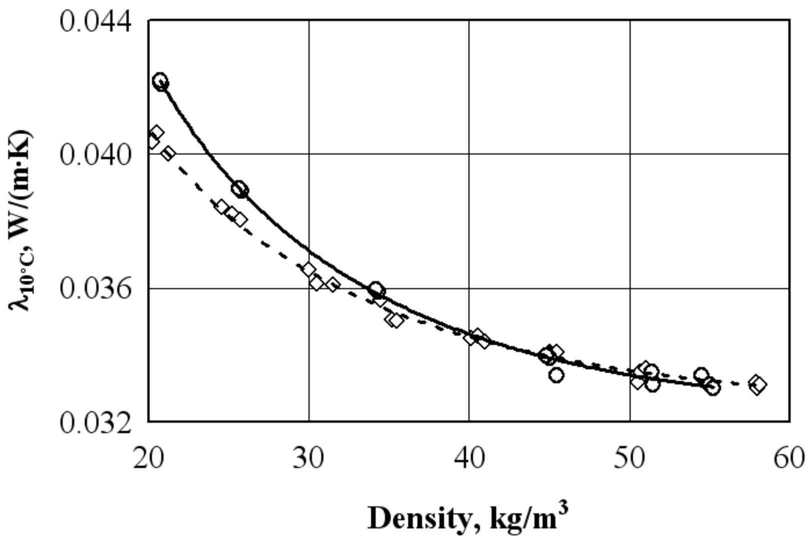

Fig. 1. Dependence of thermal conductivity on the density of specimens of 100% polylactide fibres (PLA): ○ – experimental data; (––) – regression line (equation (3)); and woollen yarn waste (Table 1, mixture No 1): ◇ – experimental data; (– – –) – regression line (equation (4))

showed that with an increase in density of approximately 2.9 times, the thermal conductivity coefficient decreased by approximately 22.1%.

Experimental research shows that the specimens of woollen yarn waste and PLA fibres have good thermal conductivity properties, thus the composition of these fibres will have a positive effect on the value of the total thermal conductivity of the composite. The experimental thermal conductivity data obtained for the woollen yarn waste and polylactide fibres specimens were described using regression equations (see Table 6. Equations (3) and (4) are derived from Equation (1)).

Test results of the thermal conductivity investigations of different compositions of the woollen yarn waste products are presented in Fig. 2.

Experimental studies show that the density variation for both compositions - thermally treated and thermally untreated - ranges from ~ 15.1 to 41.2 (Figures 2a, and 2b). The experimental values of the thermal conductivity of the composites were described by regression equations (see Table 7, Equations 5-8). When comparing the thermal conductivity of the thermally treated and thermally untreated composites (Fig. 2a) at a density of ~ 15 kg/m^3, the difference was 5.4%. With a corresponding increase in density to ~ 40 kg/m^3, this difference was 1.6%.

When comparing the thermal conductivity of the thermally treated and thermally untreated composites with yarns (Fig. 2b) at a density of ~ 15 kg/m^3, a 7.4% difference was obtained. With a density increase of ~ 40 kg/m^3, this difference was 3.3%.

To summarise the experimental data, we can state that the changes in the thermal conductivity of both thermally untreated composites remain similar. After thermal treatment of specimens of both compositions, the values of the thermal conductivity increased. This increase can be explained by the fact that PLA fibres acquire a partially vitreous structure, which also increases the thermal conductivity.

A comparison of the experimental data with the results obtained by other authors was carried out. Ye et al. [32] investigated the thermal characteristics of sheep wool and sheep wool with hemp fibres. The density of sheep wool ranged from 9.60 kg/m^3 to 25.9 kg/m^3, while that of wool with hemp fibres ranged from 9.9 kg/m^3 to 18.1 kg/m^3. They found that the thermal conductivity of sheep wool ranged from 0.0665 W/(m·K) to 0.0342 W/(m·K), whereas that of sheep wool with hemp fibres ranged from 0.0644 W/(m·K) to 0.0382 W/(m·K). Comparison of the results obtained by the authors and ours shows that the difference is quite large because the authors obtained better results of the thermal conductivity at lower densities. This difference can be explained by the fact that the authors used only sufficiently high-quality wool to produce mats by carding. Meanwhile, our composites are made from wool waste with PLA binder and are thermally treated. This difference can be stated as the influence of technological parameters on the thermal conductivity coefficient.

Jiri Zach [33] conducted a study on a hemp fibre composite. The researcher found that the thermal conductivity coefficient ranged from approximately 0.0401 to 0.050 W/(m·K), which depended on both factors: the density and the thickness of the material. We can see that the composite obtained by us has better thermal conductivity characteristics than that obtained by the Czech authors. This difference can be explained by the fact that the composite obtained by the Czech authors is not only a fibrous structure but contains hemp shives, which amount to 32% in the composite.

Number of regression equation	Number of tests (estimations)	Values of constant coefficients			S_r, W/(m·K)	$R^2_{\lambda_{10}} \cdot \varphi$
		b_0	b_1	b_2		
5	12	0.0242	0.000124	0.305	0.000354	0.993
6	12	0.0189	0.000206	0.412	0.000276	0.997
7	12	0.0183	0.000240	0.398	0.000173	0.998
8	12	0.0145	0.000320	0.486	0.000566	0.988

Table 7. Results of the statistical processing of the thermal conductivity of composites

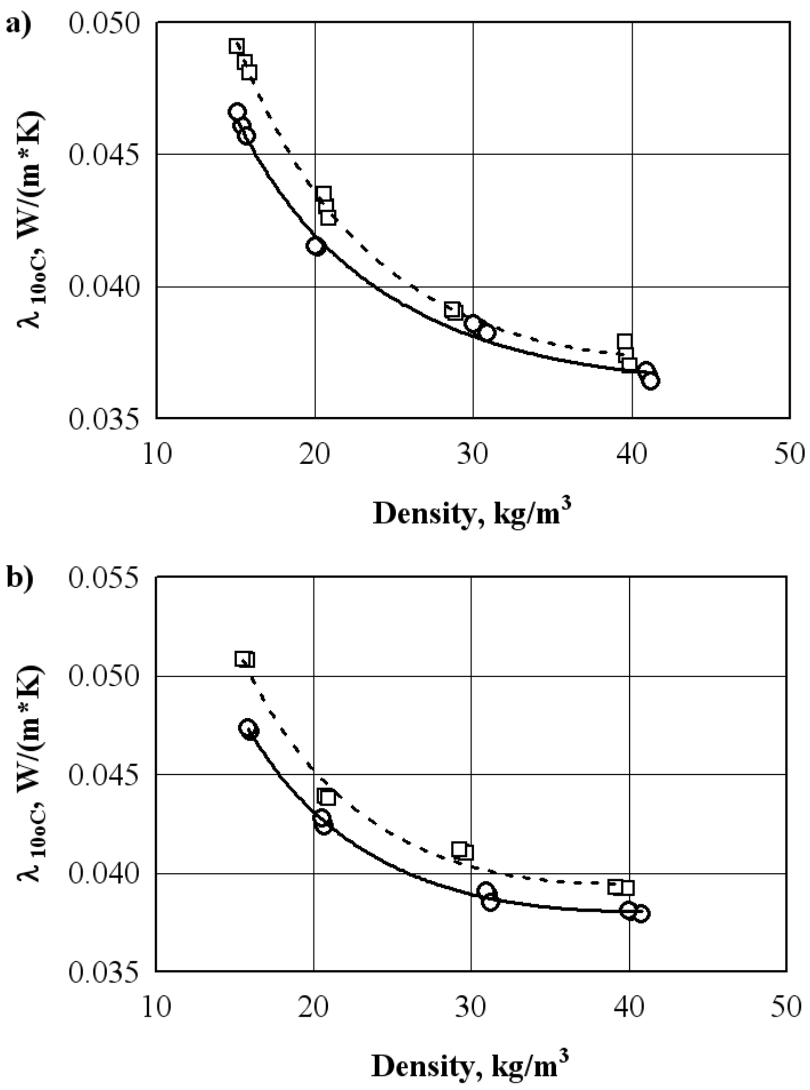

Fig. 2. Relationship between thermal conductivity and density: a) composite without added yarns (Table 1, mixture No 2); ○, □ – experimental data; (—) – thermally untreated specimen (regression line according to equation (5)); (- - -) – thermally treated specimen (regression line according to equation (6)); b) composite with added yarns (Table 1, mixture No 3); ○, □ – experimental data; (—) – thermally untreated specimen (regression line according to equation (7)); (- - -) – thermally treated specimen (regression line according to equation (8))

The authors in [34] examined the thermal conductivity of thermal insulation materials made from feather waste. They explained the low thermal conductivity as due to the low thermal conductivity of the feather fibers and to the void structure formed by air-laid processing, which effectively traps air. Asdrubali et al. [35] provided a summary of values for the thermal conductivity of different authors. Comparison of the experimental results obtained by us and other scientists shows that the differences are due to the technological parameters of material processing. It is also sometimes difficult to compare the results obtained with those achieved by other scientists due to different measurement parameters and methods [18, 36], as well as to other factors such as material density, thickness, structure, and fibre orientation.

3.2. Structure

The macro and microstructures of the composite material from the woollen yarn waste depend on several factors, the most important of which are the initial raw materials and thermal treatment parameters. Thermal treatment parameters are described by two indicators: temperature and time. Time is understood as the duration from the start of exposure of the fibres at high temperature to the start of melting of the PLA. Only by combining these two parameters can we obtain a rational structure of the composite with the best physical-mechanical properties.

The diameters of the fibres were determined by scanning electron microscopy (Fig. 3 a). The diameters of the wool fibres investigated in our work ranged from about 23 μm to 44 μm. Meanwhile, for natural fibres obtained from raw materials of vegetable origin, a large inequality in the diameters of the fibres is characteristic. The thicknesses of such fibres often varies several times in the same sample. Inequality of the fibre diameter impedes the production of composites; it is difficult to select a

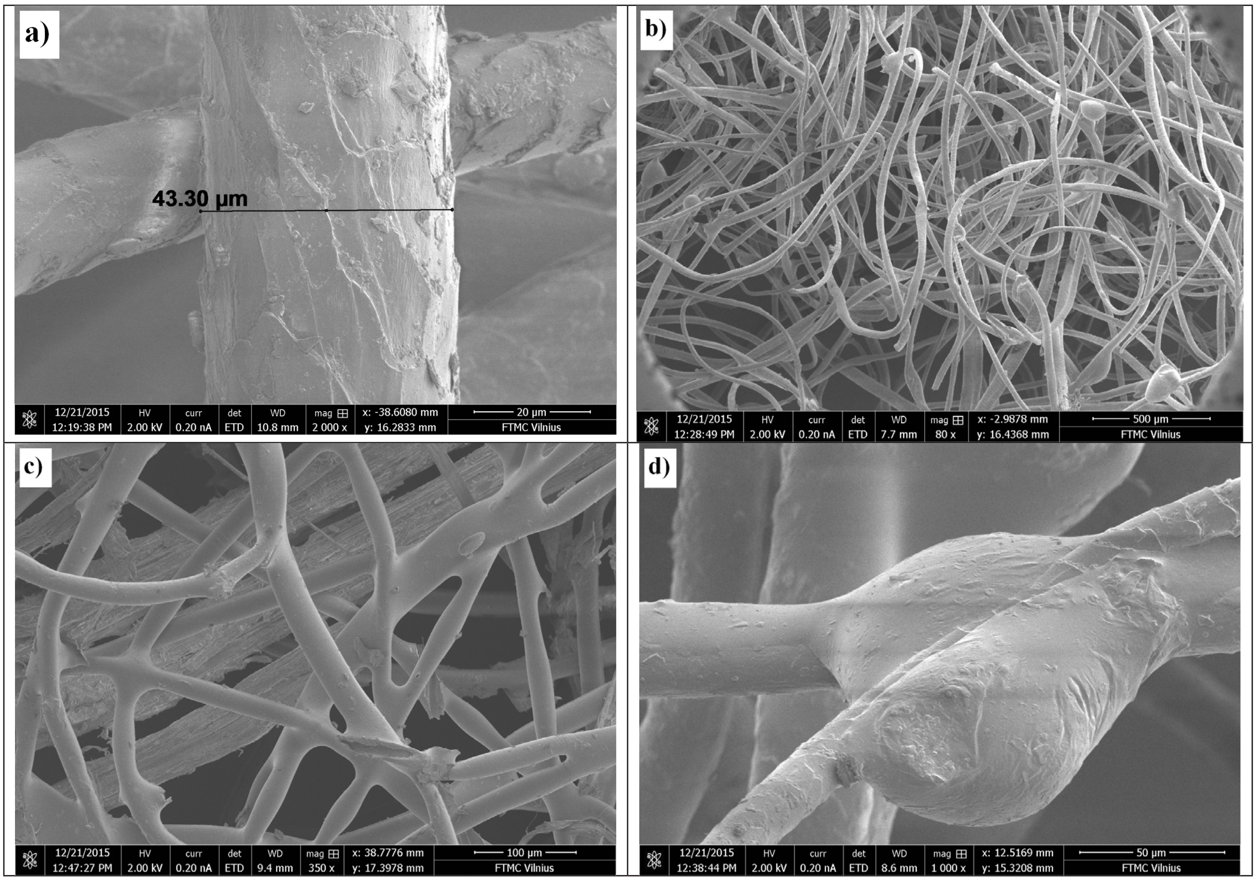

Fig. 3. Structure of fibres and contact zones of thermally treated composite (Table 1, mixture No 2): a – sheep wool fibres; b – general view of interconnected fibres of composite; c – network of interconnected polylactide fibres; d – network of interconnected sheep wool and polylactide fibres

rational amount of binding material to ensure constant properties or products, and to select production parameters.

A general view of the composite prepared is presented in Fig. 3 b. We can visually observe that contact zones are formed only in separate areas. As further analysis shows, contact zones are formed between the contacting polylactide fibres and between the polylactide and wool fibres (Fig. 3 c and Fig. 3 d). This means that the raw material must be evenly mixed to obtain a greater number of contact zones using the same amount of binder. In Fig. 3 c the structure of some polylactide fibres interconnected into a tidy network is observed. Fibres that intersect each other are bound only in their contact zones. Different types of contact zones are observed between polylactide and wool fibres (Fig. 3 d). Since the wool fibres do not melt, polylactide dissolution occurs in the contact areas of the two fibres. A drop of dissolved PLA surrounds the wool fibres and forms a contact zone.

When the temperature and time of the thermal treatment process are unbalanced, i.e., too short a duration of thermal treatment and too low a temperature, or in other cases too long a duration of thermal treatment and too high a temperature, then between different fibres, i.e., sheep wool and polylactide, unsuitable contact zones are formed. If the temperature is too low or the time too short, weak contact zones are formed between the sheep wool and polylactide fibres. When the temperature is too high or the time too long, the polylactide fibres melt suddenly and large contact zones, i.e., conglomerations of polylactide melt, are formed. In such a case, contact zones are simply formed in separate areas. Because of the large conglomerations of the binding material, the thermal properties of the composite are poor. When the thermal treatment process is proportionate, i.e., the ratio of temperature and duration of thermal treatment is rational, the best performance of wool fibres is obtained.

Plowman et al. [37] investigated the structure of sheep wool fibres. Their found that sheep wool fibres differed in diameter, which ranged from about 15µm to 50µm. The heights and patterns of the cuticle scale also revealed significant differences. In our case, the diameter of the sheep wool waste fibres ranged from about 20 µm to 45 µm.

Many authors discuss nonwoven sheep wool products without additional thermal treatment. In the production of thermal insulation products with fibrous binders, thermal treatment plays an essential role. Bulgarian researchers [38] developed mats composed of poly(L-lactic acid) (PLA) and poly(ε-caprolactone) (PCL) at various weight ratios. The thermal treatment of the fibrous materials was carried out in a vacuum oven at a temperature of 60°C. The researchers found that on increasing the PCL content in the pristine PLA/PCL mats, a denser network of interconnected fibres was formed after thermal treatment. In our case for thermal insulation materials, a denser network of interconnected fibres forms intensified heat transfer zones.

4. Conclusions

1. It was determined that about 74% of sheep wool waste, which is constituted during the production of woollen yarns, according to its composition and particle size, is suitable for reuse in the production of environmentally-friendly thermal insulation materials. The fibre content of long and medium-length fibres is about 96.1% by weight, of which 95% are sheep wool fibres.

2. The thermal conductivity of the thermally untreated composites remains similar. After thermal treatment, an increase in the thermal conductivity of both compositions is observed. This can be explained by the formation of closer contact areas between fibres, which intensifies the heat transfer via solid material.

Increasing the density of all compositions from 15 kg/m^3 to 30 kg/m^3 caused a decrease in the thermal conductivity values. In the range of densities from 30 kg/m^3 to 40 kg/m^3 , the decrease in thermal conductivity is negligible. This means that heat transfer via gases begins to decline or stops. Yarn waste used in composites does not have an impact on the thermal conductivity, or the effect is negligible.

3. Structure analysis showed that wool processing waste does not differ or differs insignificantly when comparing the parameters - diameter and appearance - of the wool fibre with those of raw sheep wool. Composite structure parameters are mostly predetermined by technological parameters, such as the uniform mixing of raw materials and the formation of rational contact zones between fibres during the thermal treatment process.

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