Textile waste as a thermal insulation material

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Thermal insulation materials provide thermal energy savings. Classic insulation materials (stone wool and polystyrene) dominate the European market, but researchers' efforts are aimed towards improving their efficiency and developing new insulation materials. They are evaluated according to their physical properties, effect on people and the environment, installation difficulty and price. In this paper a material for thermal insulation of roof construction and internal walls has been designed from apparel cutting waste and its thermal conductivity λ (W/mK) has been determined. The results show a thermal conductivity of 0.05198-0.06032(W/mK), comparable to the conductivity of standard insulation materials and insulation materials in the form of textile fibers.
Key words: *cutting waste, insulation material, thermal conductivity, thermal insulation*

1. Introduction

Since the middle of the seventies of the past century the energy crisis has directed the efforts towards conserving and reducing every form of energy, and pushed research towards finding alternative energy sources. In order to conserve thermal energy, a lot of attention has been paid to the improvement of the efficiency of thermal insulation materials and the construction of new insulation materials. At the same time, new methods for the measurement of thermal parameters are being developed [1]. The European market is characterised by the domination of two groups of insulation materials: inorganic fibrous materials- stone and glass wool (60 %), and organic foamy materials - expanded and extruded polystyrene (27 %). The remaining 13 % consist of other materials [2]. Wool, cotton, vacuum insulation materials and nano insulation materials are used as alternative materials for thermal insulation [3]. The assessment of insulation materials is an issue which needs to be analyzed from different aspects: the physical properties of the material, their effect on people and the environment, installation difficulty and price [2]. However, the most important property of every insulation material is the coefficient of thermal conductivity - λ (W/mK). Most of typical thermal-insulation materials have a coefficient of thermal conductivity λ=0.030–0.045 (W/mK) [3], but materials with a coefficient of thermal conductivity lower than 0.1 (W/mK) such as cork, wool, straw [1, 4] are also considered to be thermal insulators. Recycled textile waste can be used as a raw material for new insulation materials. Theoretically, 97 % of textile waste can be recycled. All phases of textile waste reconstruction into a new product protect the environment, in addition to saving unrenewable natural resources at same time. Recycling textile waste has ecological, as well as economic benefits, making it more popular in the past decades [5, 6]. In the countries of the European Union the production of ecological products with reduced harmful effects on the environment has become a priority. Ecological labeling of the products in the EU started with the application of EEC num. 880/92 EU Council in 1992, aiming to motivate the business sector to develop products that would fit in the scheme of ecological products [7]. As a result, companies have turned towards the production of ecological insulation materials, including insulation materials from recycled textile. “Inno-Therm”, a company from Great Britain, produces insulation from recycled industrial cotton material (denim) which is a form of safe and eco-friendly insulation. The material is processed with fire-retardant finish [8]. The French recycling company “Le Relais” which collects 45,000 tons of used textiles annually developed a thermal insulation product called Mettise. It is composed of 70 % cotton, 15 % wool/acrylic and 15 % polyester as a binder. The material is treated against fungi and insects [9]. Thermal insulation materials in the form of panels with dimensions 200x200x5 mm from polyester waste leftover from cutting materials for “Selmark” lingerie have been experimentally produced in Spain by the thermal process of heating a plate at 190 °C and applying constant pressure for 15 minutes. The preparation includes cutting the material through a mash into small pieces with dimensions of 4mm. Panels were made with different densities. The thermal insulation of these panels ranges from 0.041 to 0.053 W/mK [10]. From the introduction it is obvious that textile waste has already found a commercial use as an insulation material. Still, only waste suitable for mechanical recycling was typically used with for this purpose. For instance, denim fabric which usually has a mass of 200-400 g/m², made from rough cotton yarn with T_t=60-100tex which can be easily carded. Because of its loose structure knitted fabrics are also easily recycled by a mechanical process. In comparison, the carding of woven fabrics with compact structure is considerably more difficult. The use of greater mechanical force on polyester fabrics may cause it to melt. Taking into consideration the growing use of polyester, the idea is to use apparel cutting waste leftover from the cutting of polyester fabrics for thermal insulation in shredded, rather than fibrous form.

In this paper a new insulation material made from the textile waste of cutting polyester fabric has been designed and its thermal insulation has been determined. The goal is determining the differences in thermal insulation between recycled thermal-insulation structures obtained from textile in the form of fabric and recycled thermal-insulation structures obtained from the cutting of apparel cutting waste from polyester fabric.

2. Experimental part

2.1. Materials

Polyester fabrics of various mass and structure were used as materials for the insulation structures. The polyester fabric was shredded using a cutting machine with rotational knives. The structural characteristics of fabric A differ greatly from those of fabrics C and D. Fabric D differs from A and C because of its raw material content, as it contains 5 % Lycra® fibers. The characteristics of the used fabrics are shown in Tab.1.

Sample B obtained from knitted polyester fabric in partly fibrous form was used for comparison. Casing made of 100 % polypropylene was filled with these materials. The samples had (60x60cm) length and width and height (thickness) of 50, 70 and 100 mm. When projecting the structure commercial thicknesses of 50, 70 and 100 mm Tervola®, internal isolation material in the construction industry, were used. The quantity of apparel cuttings used to fill the casings was calculated from the fabric mass and casing volume in order to obtain a constant density of 115 kg/m³ of the non-woven textile structure (Tab.2). To secure the isolation structure it was stitched with 4 stitches along its length and width distanced on 15 cm (Fig.1), leading to a change in height, and therefore a change in density. In this manner ten samples with different characteristics were obtained (Tab.2).

Following the stitching sample thickness -h and the density-ρ changed in a different way for each sample, dependent on the filling material and its previous preparation (Tab.3). The change of the thickness causes change of volume, consequently the density of the sample, which presents the relation between the mass and volume of the sample filling (Tab.3).

2.2. Determining thermal insulation

To determine the coefficient of thermal conductivity-λ the instrument Heat flow meter FOX600, a product

Tab.1 Structural characteristics of used fabrics

Fabric	A	C	D
Thickness (mm)	0.16	1.2	1.6
Cv (%)	2.17	1.80	1.38
Mass per unit area (g/m²)	92	245	272
Cv (%)	3.13	1.16	1.38
Warp density (cm⁻¹)	74	37	44
Weft density (cm⁻¹)	45	25	28
Warp count (tex)	7.4	36	36
Weft count (tex)	7.4	36	36

Tab.2 Samples characteristics and preparation

Sample	Type of material	Raw material content (%)	Fabric form	Quantity of fabric (kg)	Size (cm)
A_1	cutting waste	100 PES	partially cut, pieces with different size	2.070	60x60x5
A_2	cutting waste	100 PES	cut into small pieces with different size	2.070	60x60x5
A_3	cutting waste	100 PES	in original form without preparation	2.898	60x60x7
A_4	cutting waste	100 PES	in original form without preparation	4.140	60x60x10
B	knitted fabric partially fibrous	70/25/5 PES/cotton/ Lycra®	mechanical recycling partially fibrous	2.070	60x60x5
C_1	cutting waste	100 PES	cut, pieces' average dimensions 6x4cm	2.070	60x60x5
C_2	cutting waste	100 PES	cut, pieces' average dimensions 8x4cm	2.070	60x60x5
D	cutting waste	95/5 PES/Lycra®	cut, pieces' average dimensions 8x4cm	2.070	60x60x5
ABC	cutting waste -fabric A knitted fabric partially fibrous -fabric B cutting waste -fabric C		A- cut, pieces with different size B- knitted fabric partially fibrous C-cut, pieces' average dimensions 6x4cm	0.690 0.690 0.690 S=2,070	60x60x5
ABD	cutting waste -fabric A knitted fabric partially fibrous -fabric B cutting waste -fabric D		A- cut, pieces with different size B- knitted fabric partially fibrous D- cut, pieces' average dimensions 8x4cm	0.690 0.690 0.690 S=2.070	60x60x5

of the company Lasercomp, with WinTherm 32 Version 2.30.21 software was used (Fig.2). Testing was conducted following ASTM C518 and ISO 8301 standards. The general principle of the FOX600 heat flow meter instrument is based on one-dimensional Fourier' law (1):

$$q = -\lambda\left(\frac{dT}{dx}\right) \quad (1)$$

where:
q – heat flux flowing through the sample (W/m^2)
dT/dx – temperature gradient on the isothermal flat surface
λ – coefficient of thermal conductivity (W/mK).
The sample is placed between two plates with different temperatures until the temperature field stabilizes.
The instrument automatically measures the sample thickness, whereas the temperature gradient can be determined by measuring the difference between temperatures of the hot and cold plates $\Delta T = T_h - T_c$ and the thickness of the sample Δh, where T_h (K) is the temperature of the hot plate and T_c (K) is the temperature of the cold plate. Before testing the instrument must be calibrated using standard samples with a known thermal conductivity value. The electric signal from the transducer Q (mV) is proportional to the heat flux q (2):

$$q = \frac{\lambda_{cal}(T_{cal})\Delta T_{cal}}{\Delta h_{cal}} = S_{cal}(T_{cal})Q \quad (2)$$

Since the transducer's physical properties change with temperature, calibration of the instrument in order to obtain the calibration factor, Scal, is necessary. The calibration factor is given in either $Wm^{-2}\mu V^{-1}$ or $Wm^{-2}mV^{-1}$. As each of the two transducers has its own temperature, two separate sets of calibration factors are measured. The calibration factors (S_{cal}, T_{cal}) are the instrument's characteristics.
They are used for calculating thermal conductivity -λ (3) during the test:

$$\lambda_{test} = \frac{S_{cal}(T_{test})Q\Delta h}{T_{test}} \quad (3)$$

Because each plate has its own temperature the calibration factors should be calculated for a plate's actual tem-

Fig.1 New insulation structure

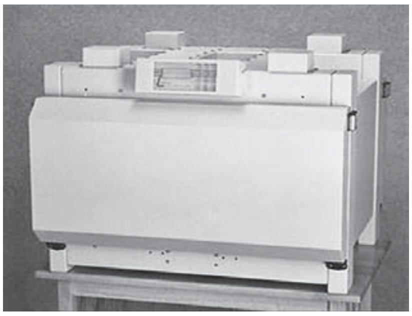

Fig.2 Heat flow meter FOX600

perature, obtaining two λ values. By averaging the two thermal conductivity values the final result of thermal conductivity test is acquired [11]. Based on the measured value of the coefficient of thermal conductivity λ and equation (4) the value of thermal insulation R of the sample is determined [12].

$$R = \frac{h}{\lambda} \quad (m^2K/W) \qquad (4)$$

where:
h -thickness (m), λ -coefficient of thermal conductivity (W/mK)
Tab.3 shows the results from the thermal conductivity tests (*λ*), the value of the thermal insulation (*R*), in addition to the thickness (*h*) and density (*ρ*) of the sample.

3. Discussion

Research was conducted in many directions. The main goal was to determine how the thermal insulation structures from apparel cuttings compare to standard insulation structures (inorganic fiber and foamy structures), along with the insulation materials from textile fibers. Furthermore, the effect of the dimensions of the apparel cuttings, fabric structure and the content of Lycra® on the thermal insulation of apparel cuttings insulation structures was researched. The measured values of the coefficient of thermal conductivity-λ of the samples with different heights ranged between 0.0520-0.0603 W/mK. The obtained λ values are similar to standard insulation materials (λ=0.030-0.045W/mK), as well as commercial insulation structures from textile fibers (λ=0.039-0.041W/mK). Some of the samples show better thermal insulation properties than thermal polyester panels obtained from thermal recycling which have λ=0,04-0,053 W/mK. The Heat flow meter FOX600 automatically determines the height, i.e. thickness, of the fabric under standard load. From Table 3 it is visible that due to stitching the actual height of the samples varied significantly, ranging from 21.61 to 45.99, while the density ranged from 127 to 265.4 kg/m³. Figures 3 and 4 show the change of thermal conductivity-λ with the change of thickness-h and density-ρ of each sample. A significant correlation was not found between the thermal conductivity –λ and the thickness-h nor density-ρ.
The thermal conductivity of the samples ranged from 0.0520 W/mK (sample A_2) to 0.0601 (sample A_4), while the values of thermal insulation ranged from 1.658 m²/WK (sample D) to 1.924 m²/WK (sample A_2). The coefficient of variation of thermal insulation between the samples was 5.44 %. The height (thickness) of samples is crucial for determining thermal insulation. Fig.5 shows the correlation between the thermal insulation R and the thickness h of the samples. A high correlation (0.96) is noticable between the thickness h and the thermal insulation R.
In order to assess the effect of the dimensions of the apparel cuttings, the mass of the fabric and the Lycra® fiber content of the waste, samples must have the same thickness. Since thermal insulation is directly proportional with thickness, the thickness of all the samples was set to 100 mm. The termal insulation of all the samples with thickness of 100 mm is marked as R*. Samples marked as A were made of waste from the same fabric, but with different dimensions of the cut pieces of the fabric. The fabric with the smallest pieces A_2

Tab.3 Physical and thermal characteristics of the samples

Sample	h (mm)	ρ (kg/m³)	λ (W/mK)	R (m²/WK)	R* (m²/WK)
A_1	26.5620	215.6	0.0529	0.5017	1.889
A_2	27.6350	209.1	0.0520	0.5316	1.924
A_3	35.5410	226.4	0.0546	0.6505	1.830
A_4	45.9990	249.4	0.0601	0.7654	1.664
B	45.2370	127.0	0.0592	0.7641	1.689
C_1	22.9550	249.4	0.0553	0.4151	1.808
C_2	21.6150	265.4	0.0543	0.3981	1.842
D	33.0640	173.9	0.0603	0.5483	1.658
ABC	34.9400	164.3	0.0536	0.6519	1.866
ABD	35.3000	163.0	0.0533	0.6623	1.876

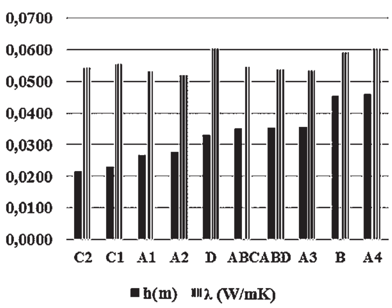

Fig.3 Thickness - *h* and thermal conductivity - *λ*

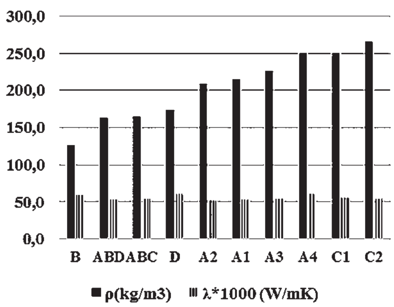

Fig.4 Density - *ρ* and thermal conductivity - *λ*

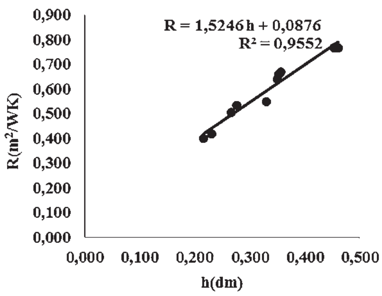

Fig.5 Correlation between the thickness - h and the thermal insulation - R of the samples

shows a higher thermal insulation R*=1.924 m²/WK compared to the sample A_4 made from apparel cuttings that were not shredded, with R*=1.664 m²/WK. Samples marked as A were made of the fabric with the smallest fabric mass have an insignificantly better thermal insulation compared to samples C and D, where a fabric with a greater mass per unit area was used. Moreover, it is noticeable that the presence of Lycra® in the waste decreased the thermal insulation of samples B and D, while in sample ABD the presence of component A without Lycra® dimineshed the tendency. Combined samples of knitted fabric partially in the form of fiber and cut waste ABC and ABD have very similar thermal insulation values (R*=1.866 m²/WK for sample ABC and R*=1.876 m²/WK for sample ABD) which means that the presence of a third different component, C and D did not have a significant influence on the thermal insulation.

4. Conclusion

Cutting waste from polyester fabrics is usually thrown away which is a loss of valuable resource, on top of environmental pollution. Instead, it can be used to make thermal insulation material. The production process is simple: shredding the waste into small pieces and consolidation of the structure, in this case with sewing. The structure is cheap to make and has good thermal insulation properties. The values of its thermal insulation are comparable to the values of the commercial insulation material, although in order to obtain the same insulation this new structure requires greater density, i.e. greater quantity of fabric. Considering that waste is used this is not a problem, but, on the contrary, a great opportunity to decrease the pollution of the environment and produce eco-friendly insulation for internal double walls in buildings.

References:

[1] Horga G. et al.: Investigation on determining the coefficient of thermal conductivity to textile materials recoverable used for thermal protection of hot pipelines, Tekstil ve Konfeksiyon 23 (2013) 2, 94-99

[2] Papadopoulos A.M. et al.: Composite insulating materials as a tool for the reduction of cooling loads, International Conference, Passive and Low Energy Cooling, Santorini, Greece (2005), 807

[3] Papadopoulos A.M.: State of the art in thermal insulation materials and and aims for future developments, Energy and Buildings 37 (2005) 77-86

[4] http://www.ravago.hr/products/toplinske-izolacije/ (accesed: 27.12.2012.)

[5] Jordeva S. et al.: Investigation on apparel waste management in Macedonia, In:10th Symposium Novel technologies and economic development, 22-23 Oct. 2013, Leskovac, Serbia

[6] Jordeva S. i sur.: Kvalitativna i kvantitativna analiza konfekcijskog otpada u Makedoniji, Savremene tehnologije 2 (2013) 1, 82-88

[7] Ministerstvo za životna sredina i prostorno planiranje na R. Makedonija, Fizibiliti studija za donesuvanje na nacionalni kriteriumi za dodeluvanje na ekološka oznaka za tekstil, 2008

[8] http://www.recovery-insulation.co.uk (accesed: 27.11.2012)

[9] www.lerelais.org/Isolant-Metisse (accesed: 27.11.2012.)

[10] Valverde C. et al.: Development of new insulation panels based on textiles recycled farics, Waste and Biomass Valorization 4 (2013) 1, 139-146

[11] http://www.lasercomp.com/Tech%20Papers/Methods/Heatlow%20Meter%20Theory%20of%20test%20%20method.pdf (accesed: 27.12.2012)

[12] Oglakcioglu N., A. Marmarali: Thermal comfort properties of some knitted structures, Fibres&Textiles in Eastern Europe 15 (2007) 5-6, 94-96