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Research Article

Sustainable Thermal Insulation Derived from Recycled Textile Waste

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Abstract

The textile industry is one of the oldest industries and the third most important industry branch in Macedonia. It has had a steady increase in production over the years. Growing production line proportionally generates textile waste. Although it is terminologically categorized as waste, textile waste can be a valuable resource and is one of the textile industry's main challenges. Textile waste, appropriately treated with the possibilities offered by the recycling process or used as a clean waste, can find multi-faced application in different construction areas. This paper covers research that examines the possibilities of applying textile waste in the field of thermal insulations in buildings. The focus is on developing thermal insulation solutions applied in sustainable and ecologic buildings. Applied thermal insulation has a primary impact on reducing electricity consumption and greenhouse gas emissions associated with indoor air conditioning. That would mean that buildings incorporating appropriate thermal insulation offer greater comfort, directly increasing the quality of life. This is an additional economic-environmental dimension. According to the experimental testing, the thermal conductivity coefficient of the textile waste is obtained at 0.039 W/m·K.

Its value defines a thermal insulation material suitable for the purpose and has approximate values to the other materials usually used for thermal insulation in buildings. Implementing a product made of textile waste with appropriate performance would bring economic benefits to the industry and open new job opportunities.

Keywords
Textile waste; recycling; thermal insulation; thermal conductivity

1. Introduction

The performance of buildings in terms of energy consumption depends on the thermal efficiency of their envelopes. If the intended components and materials in the envelope are not properly designed and installed, the heat leakage will compromise the overall energy consumption. Good insulation material is the fastest solution for drastically reducing consumption and greenhouse gas emissions. A wide range of thermal insulation materials guarantee low thermal conductivity and adjust the heat exchange between the external and internal space, ensuring ideal comfort and convenience in the living space, equally during winter heating or summer cooling. However, some of them, in their production process, even during the life cycle, still do not behave in a friendly way towards the environment, consuming energy in all phases of the life cycle [1, 2]. The current situation about the available natural resources, the quality of the materials, and the cost inevitably imposes a new, modern approach to the energy efficiency of the buildings, the impact on the environment, potential waste, etc. Namely, the new approaches are oriented toward the energy-efficient and sustainable design of buildings while applying local building materials and reusing of materials and potential waste [3].

Every aspect of our lives creates waste, but not all waste is garbage because it contains valuable resources that can be reused. The constant accumulation of waste, apart from being a problem for the environment, is also a problem for people's public health [4]. With increasing people's awareness of environmental protection, the trend, but also the need to develop ecological materials obtained from renewable sources, is emerging more and more often. Recently, special emphasis has been placed on such materials used in the construction industry, and they have a promising future. Concrete and steel are the most commonly used materials in buildings However, the high costs of their production lead science to research and development of composite materials obtained by recycling textiles, wood, etc., materials, which will also contribute to comfort in the buildings, and through their characteristics will provide thermal and acoustic insulation of the building.

Due to the world's population growth and the improvement of living standards, the global consumption of textiles is constantly increasing [5], which affects the amount of waste generated. Seen from the point of view of clothing waste per inhabitant on an annual level, the clothing industry leaves behind a significant amount of waste due to the increased consumption of fashion textiles. Although this textile waste is a valuable resource because it is new, clean with retained physical and mechanical properties, does not require any treatment before recycling, and is almost 100% recyclable [6], most of this waste is thrown away. It ends up in landfills together with other municipal waste. According to Briga-Sa A. et al. [7], around 5.8 million tons of textiles are discarded by consumers per year in the EU, which is post-consumer waste. Only 1.5 million tons (25%) of the 5.8 million tons are recycled by charities and industrial enterprises annually. The remaining 4.3 million tons goes to landfill or municipal waste incinerators. Adding to this type of waste, there is also textile industrial waste, i.e., post-industrial waste (pre-consumer waste) that includes fiber, yarn, and fabric waste [8]. The EU textile industry generates approximately 16 million tons of waste annually, and above 70% of this waste is disposed of into landfills or is incinerated [6].

The textile industry stands out as one of the traditional industrial branches in the Republic of Macedonia and has a significant role in the country's economy. Apparel production accounts for 12.73% of total industrial production, and textile production accounts for almost 15%. It participates with 15.2% of the total gross domestic product and 21.8% in the industrial one. The textile industry participates with 26% of the total export and employs 28% of the total workers. More than 300 clothing companies in Macedonia export about 1,400,000 pieces of clothing per month. As a result, a huge amount of textile waste remains in the country [9].

Landfilling contributes to environmental pollution, groundwater contamination, and the creation of powerful greenhouse gases. The decomposition of degradable textiles produces methane; organic textiles generate ammonia upon decomposition, while synthetic textiles are non-degradable and therefore accumulate in landfill sites [10]. Considering the consumption of water and the pesticides and artificial fertilizers used, it is known that the textile industry is one of the sectors that pollute and generate the most waste [11]. All this actualizes the need to carefully manage the substantial textile waste and engage as much as possible with recycling/reusing practices. Detailed studies regarding the environmental impact and benefits of textile reuse and recycling can be found in [12, 13].

Textile waste is terminologically categorized as waste. Nevertheless, it represents a valuable resource, which provides the possibility of applying the recycling procedure, i.e., the possibility of reuse depending on the new characteristics and their application. Considering that the construction sector has a significant energy consumption, materials, and other resources, it is especially important to encourage the application of sustainable and recycled materials. In the world literature, there are many research papers dedicated to textile waste and its reuse, in which an account of the application of the waste in various areas is given, including the application as a thermal insulation building material.

Many studies show that the thermal properties of reused materials are comparable to those of standard insulation materials. Briga-Sa et al. [7] investigate the thermal properties of woven fabric waste and sub-waste. El Wazna et al. [14] conducted an experimental and numerical investigation on the thermal performance of nonwoven textiles obtained from raw wool, carpet wool, spinning, and knitting acrylic waste. Hadded et al. [15] studied the thermal conductivity and diffusivity of two samples, linens and tablecloths, produced by shredding and mixing the waste. Different woven and recycled nonwoven textiles are also investigated by Peña et al. [16], Bhattacharjee et al. [17], Antolinc et al. [18] and Mancasi et al. [19] using thermal properties. Sadrolodabaee et al. [20-22], explore the possibility to use textile waste in cement-based composites through dedicated experimental work on mechanical and durability properties but also on the serviceability aspects: thermal and acoustic properties and fire resistance.

This research focuses on developing a solution for the thermal insulation of buildings that will be sustainable and ecological, i.e., nature friendly. The thermo-technical properties of nonwoven textile waste were measured based on which its ability for thermal insulation is defined.

2. Materials and Methods

The synergy of science and domestic economy synthesizes the knowledge about the properties of quality material for thermal insulation found in non-woven textile waste from the domestic textile industry. The studied material is textile waste, mainly polyethylene waste, provided by the factory.

Textile waste could be divided into two types: a) unusable textile products that are categorized as old and worn, i.e., finished textile products for which the period of use has passed; b) waste generated in the production processes of yarns and fabrics, as well as textile waste resulting from the production of clothing and other textile products (residues that occur during the cutting process, etc.).

Recycling textile waste implies chemical, mechanical and thermal purification and removal of unwanted components of textile waste. The first step is the process of collecting textile waste, its transportation, storage, and sorting. Afterward, the recycling procedure follows, representing a complete technological - production process. The result is a felt, which is usually pressed with heated plates at a temperature of about 190°C and constant pressure. This way, thermal insulation panels are formed with dimensions depending on the requirements. These products are made from recycled textile waste and about 7% polyester, which serves to connect the textile fibers by interweaving them during the thermal treatment process. Therefore, recycled textile waste does not use a special chemical or another binder to maintain the integrity of the insulating structure.

Another way to treat the felt is by threading, which ensures its integrity as a whole. It is in the form of rolls depending on the isolated building or element.

This research proves the thermal conductivity of the new recycled material in both types, providing guidelines for its application in the construction industry. The processed textile waste would be in the form of insulation panels: ordinary felt, quilted insulation felt for thermal and acoustic insulation, rolls, geotextile, and other insulation materials.

2.1 Testing the Thermal Conductivity of Waste Textile

2.1.1 Principles of the Testing

The property of the material to conduct heat through itself at a certain temperature difference between its two opposite surfaces is called thermal conductivity. The thermal conductivity coefficient λ characterizes this property. The values of the thermal conductivity coefficient are variable for the same material and depend on the volume mass of the material, porosity, chemical composition, moisture content , the material, the temperature of the material, etc.

The thermal conductivity coefficient is determined experimentally, in laboratory conditions. The instrument for measuring thermal conductivity HFM (Heat Flow Meter) 436/3 is intended for measuring the low and moderate thermal conductivity of materials used for thermal insulation. It has a temperature module in the range of -20°C to +100°C for testing material samples with dimensions of 300 × 300 × (5-100) mm.

The principle of the test, using the standardized machine, is based on the measurement of the heat flow through the sample, which is achieved with special heat flux sensors [23]. The heat flux is calculated according to Fourier's law:

$$\dot{Q} = \lambda A \frac{\Delta T}{\Delta x} \quad (1)$$

where:

Δx - is sample thickness

ΔT – the temperature gradient

A - surface area through which heat passes

One or two heat flow sensors measure the heat flow through the sample. The heat flow sensor signal (in volts, V) is proportional to the heat flow through the sensor. In the measuring instrument, the surface of the heat flow sensor represents the surface through which the heat flows, and it is the same for all samples. Therefore,

$$\dot{Q} = N \cdot V \quad (2)$$

where N is a calibration factor relating the voltage signal of the heat flow sensor to the heat flow through the sample. Solving the above equations (1) and (2) in terms of λ, the thermal conductivity is obtained:

$$\lambda = N \frac{V \Delta x}{\Delta T} \quad (3)$$

2.2.2 Preparation of Samples

Tested materials are felt rolls with a relatively soft material structure. Two types of non-woven textiles from recycled textile waste were tested: the first one was an ordinary felt with a constant bulk density. In contrast, the second felt was double-sided coated and embroidered, ready for use in the textile industry. All samples were kept at the same temperature of +22°C and relative humidity of 50%.

Ordinary Felt. Three samples of ordinary felt, prepared according to a standard procedure, were tested, Figure 1a. All three samples were prepared with dimensions of 300 mm × 300 mm × 10 mm, by the recommendations for the instrument. The thickness of the samples was determined according to the MKS EN ISO 9073-2 standard [24], while the mass was measured with an electronic scale according to the MKS EN 12127 standard [25]. According to these two measured sizes, the density of the material [kg/m^3] was determined.

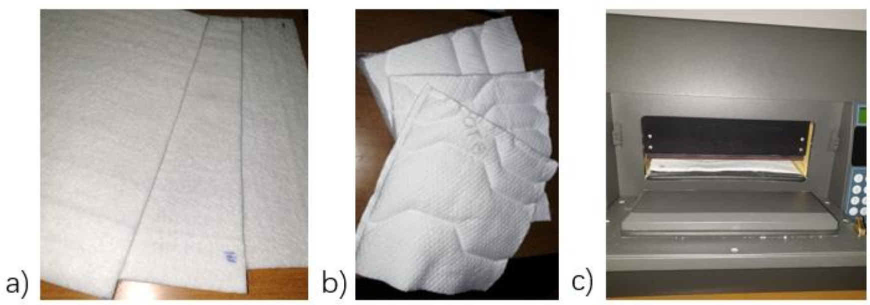

Figure 1 a) Samples of ordinary felt; b) coated felt; c) sample placed in the testing instrument.

Coated Felt. From the roll of coated felt, which has a relatively softer structure than the previous one, three test samples, were prepared with dimensions 300 × 300 × (20-27) mm, presented in Figure 1b. The density of all three samples is different, as well as their thickness, which is a result of the inhomogeneity of the material.

3. Results

The results for the three samples of ordinary felt are shown in Table 1 and Figure 2. Then an average value for the thermal conductivity coefficient of the three waste textile material samples was calculated, which shows that the coefficient of thermal conductivity is $\lambda = 0.0394 \approx 0.039$ W/m·K.

Table 1 Densities and thermal conductivities of samples of ordinary felt.

Sample of ordinary felt	Mass [g]	thickness [cm]	density [kg/m^3]	Thermal conductivity λ [W/m·K]
I	34.2	0.95	40	0.0391
II	36	1	40	0.0385
III	36	1	40	0.0408

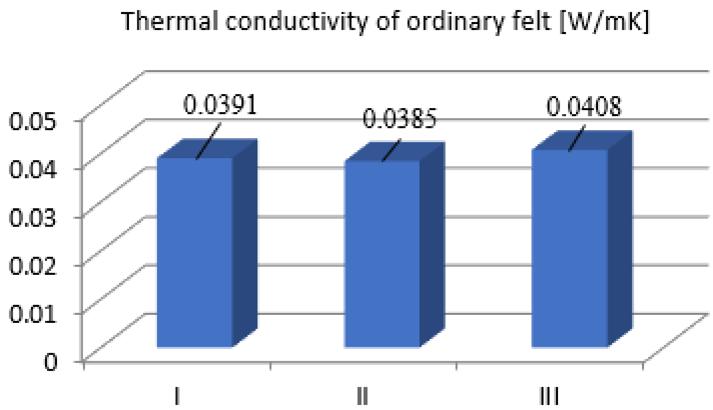

Figure 2 Thermal conductivity of the samples of ordinary felt.

Samples of the coated felt showed higher values of thermal conductivities, as presented in Table 2 and in Figure 3. The average value of their thermal conductivity is $\lambda = 0.04191 \approx 0.042$ W/m·K.

Table 2 Densities and thermal conductivities of samples of coated felt.

Sample of coated felt	Mass [g]	thickness [cm]	density [kg/m^3]	Thermal conductivity λ [W/m·K]
I	70.27	2	38.88	0.0431
II	66.62	2	36.66	0.0424
III	60.73	2.7	24.99	0.0402

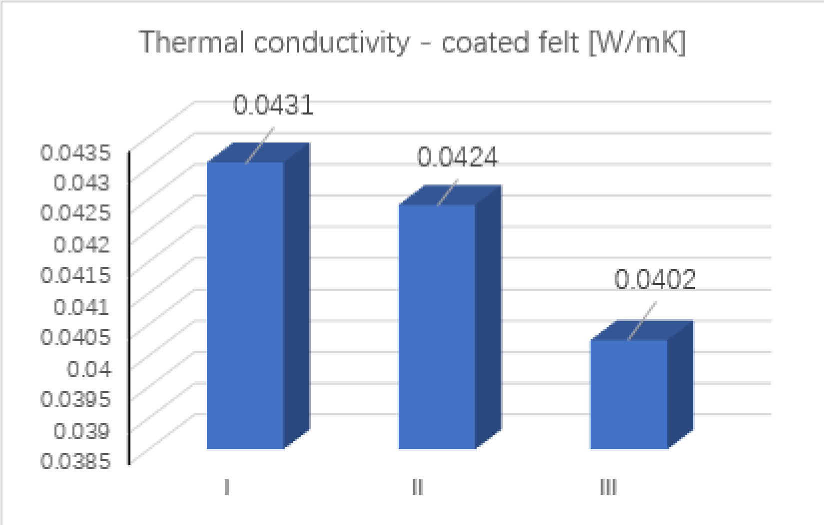

Figure 3 Thermal conductivity of the samples of coated felt.

4. Discussion

The samples of coated felt from the second test have a greater thickness than the samples of ordinary felt from the first test but a lower density. The samples of test no. 1 were visually much more compact compared to test samples no. 2, which is also indicated by the uniform mass for the given thickness of the test samples.

Ordinary uncoated nonwoven felt has a lower thickness, and a higher density than the other coated felt material. Based on the tests performed and the results obtained, it can be stated that the mean value of the coefficient of thermal conductivity of test samples no. 1 is 0.0394, and for the test samples no. 2 is 0.0419. Both materials have the same origin and structure, so the results obtained are generally close to each other.

The lower thermal conductivity of ordinary felt is due to its compactness, homogeneity, and greater uniformity of structure. Although the second material is more porous and has a lower volume mass (density), it is coated with another type of material, increasing its thermal conductivity. The third sample of the coated felt, with lower density than the other two, exhibited a lower and better value for thermal conductivity. It has a lower density than the first sample by about 35.7% and presented lower conductivity of 6.6% than the first sample. The test samples were ideally dry at the time of testing; therefore, in this case, the humidity did not affect them.

The obtained value of the thermal conductivity coefficient of waste textiles, $\lambda = 0.039$ W/m·K, shows that, compared to other conventional materials for thermal insulation, textile waste (recycled with a new shape and dimension) can find its place and justification among other insulating materials.

Recycled textile waste has a coefficient of thermal conductivity within the limits of the coefficient of thermal conductivity that characterizes traditionally used thermal insulation materials, as presented in Figure 4.

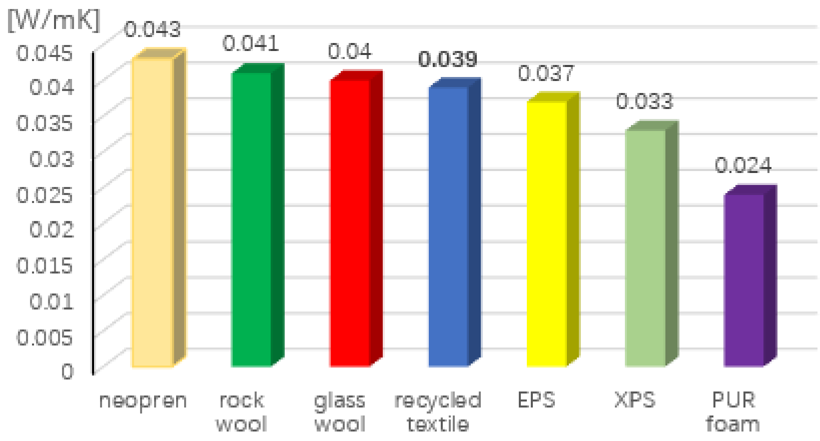

Figure 4 Recycled textiles compared with other insulating materials.

Determining the size of the coefficient of thermal conductivity of the recycled material from textile waste and its satisfactory value means that it represents an economical solution in the field of application as thermal insulation of buildings. This proves that cheaper thermal insulation materials can be offered on the market, which will reduce the costs of the construction industry, and with comparable and possibly better thermo-technical properties compared to traditional materials.

Based on the performed laboratory tests of the recycled textile waste, results of clear scientific and practical value were obtained. They generate appropriate recommendations and conclusions that would find practical application in the future.

5. Conclusions

Due to the size of the textile industry, proportional to the textile waste it generates, there is a need to transform the textile waste into a product with an appropriate purpose. At the same time, it does not pose a potential threat to the environment.

The obtained value of the coefficient of thermal conductivity of the ordinary textile waste felt, $\lambda = 0.039$ W/m·K shows that, compared to other conventional thermal insulation materials, textile waste (recycled with a new shape and dimension) can find its place and justification among other insulating materials.

The satisfactory value of the coefficient of thermal conductivity of recycled material from textile waste means that it represents an economical solution in the field of application as thermal insulation in buildings because it is a matter of using existing waste and not a natural resource. This means that cheaper thermal insulation materials can be offered on the market, which will reduce the costs of the construction industry, and with comparable and even better thermomechanical properties compared to traditional materials. Finally, this novel nonwoven textile waste material was patent protected under the market name “Isonet." Its implementation with the appropriate performance would benefit the industry economically and open new job opportunities.

The built-in thermal insulation from recycled waste textiles increases the value of the building, the quality of living, and the comfort of buildings. It directly impacts energy savings, i.e., reducing heating costs, a parameter that is of particular importance, both from an economic point of view and from the point of view of preserving the environment.

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Author Contributions

All three authors have contributed equally in the research, testing, analysis and writing a paper.

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Competing Interests

The authors have declared that no competing interests exist.

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