Development of acoustic insulating materials from recycled textile fiber

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Abstract. Nowadays, there is an increasing demand for recycling materials and hence for greater environmental friendliness. The issue of waste management and recycling is a very actual topic in the society of most developed countries. One area where the vast amount of waste is generated every year is the textile industry. Textile waste (old clothing, fashion accessories, car upholstery, home textiles and other textile products) is most often made up of a combination of different types of natural fibers (cotton, silk) and man-made fibers (polyester, viscose). Thanks to the large amount of this waste and recycling technologies available, the secondary textile fibers are an interesting secondary raw material that can be used for the production of thermal and acoustic insulators. The article describes research results in the development of medium and heavy insulating mats usable in vertical constructions and floating floor structures.

1. Introduction

In order to assure protection against the adverse effects of noise and vibrations, a quality design of building construction and the use of high quality acoustic insulating materials is needed during the execution of new constructions and reconstruction (especially in civil housing construction). Acoustic insulating materials help to reduce unwanted noise spreading through dividing constructions (horizontal partition structures, internal partitions, building envelope), or provide sound absorption from surrounding areas for technology and other devices with increased noise levels.

Problems with the spread of noise in the area of horizontal and vertical partition structures are covered by the standard ČSN 730532 „Acoustics - Protection against noise in buildings and evaluation of acoustic properties of building elements - Requirements“. The last valid amendment to this Z3 standard occurred in 2017, where conditions for hygienic use of buildings were changed. When assessing acoustic insulating properties of structures, impact insulation and airborne sound insulation are assessed in insulators. From the material point of view, the low dynamic value of the used insulator is important to achieve high impact sound insulation. For airborne sound insulation, it is important to have a high sound absorption value of the insulator in the frequency spectrum of the sound insulation band [1–6].

Textile recycling is a very complicated operation, but due to the constant growth of textile waste, it is essential to make this technology more efficient and use it more effectively. After careful sorting and defibering of textile waste it is possible to obtain a high quality secondary raw material, which can be used, among other things, for the production of acoustic and thermal insulation materials with very good utility properties. Such prepared insulators are widely used and offer an alternative to traditional
insulating materials. The article describes insulators made of purely synthetic PES fibers or a combination of polyester and cotton fibers that have been thermally bonded with bicomponent fibers.

2. Acoustic insulation materials from textile fibers

The joint research by Retex and Brno University of Technology is attempting to find use of different types of textile waste, which is very difficult to use in other applications within the textile industry, for the production of thermal and acoustic insulation in the construction industry. In the case of acoustic insulation, the most important insulators are for insulating internal partitions, as well as insulators for the construction of floating floors.

Two types of artificial synthetic fibers (recycled textiles) were selected for the production of test samples. These were crushed carpet edges and torn filters. The microscopic analysis and determination of fiber thicknesses and lengths were performed on samples of recycled fibers using the VHX-950F digital microscope. At the crushed ends, the thickness of the individual fibers ranged from 25 to 40 µm and the length corresponded to the chopping at 15 mm. The fibers were smooth, dark in color and slightly curved. The detail of individual fibers can be seen in figures 1 and 2 [7–9].

![Figure 1. Length of the crushed edge fibers.](image1)

![Figure 2. Thickness of the crushed edge fibers.](image2)

For torn filters, the fiber thickness ranged from 10 to 15 µm. The length of these significantly thinner fibers was in the range of 15 to 25 mm. The fibers had a rough surface, a light color, and were more curved than the crushed edges. The fibers can be seen in figures 3 and 4.

![Figure 3. Length of the torn filters fiber.](image3)

![Figure 4. Thickness of the torn filters fiber.](image4)

Homogenization of these two types of fibers resulted in the formation of the mixture that forms the main skeleton of the samples described in this article, see figure 5.
Figure 5. A mixture of crushed edges and chopped filters.

3. Preparations of test specimens

Five insulators were proposed in the experimental work and they were divided into two groups:

1. The first group was designed for vertical constructions and the samples were of medium to higher bulk weight. The main objective was to determine the influence of the bulk density on the sound absorption of the individual types of samples.

2. The second group of insulators was designed for the construction of floating floors, these being high density bulk insulators. In this case, they were high density bulk samples, which differed from each other mainly by their thickness.

All samples had the same raw material composition, namely 80% of the fibers (crushed edges, chopped filters) and 20% bicomponent binder fibers. Sample production was performed by the thermal bonding method and the design composition of the individual insulators is shown in table 1 below.

Table 1. Recipes and design features of individual test specimens.

| Sample number | Basic weight [g/m²] | Production density [kg/m³] | Thickness [mm] | BiCo | Composition [%] |
|---------------|---------------------|-----------------------------|----------------|------|-----------------|
| 1. Group      |                     |                             |                |      |                 |
| (vertical     | 1 5000              | 145                         | 35             | 20   | 40              |
| structures)   | 2 5000              | 100                         | 50             | 20   | 40              |
| 3             | 5000                | 50                          | 100            | 20   | 40              |
| 4. Group      |                     |                             |                |      |                 |
| (use in floor | 4 2000              | 200                         | 10             | 20   | 40              |
| constructions)| 5 4000              | 200                         | 20             | 20   | 40              |

After thorough homogenization, the fibers were deposited on a conveyor, on which a fiber mat was formed by the layering of material. The fibrous insulating mat was transported via the conveyor to the baking furnace, where the material is densified at the desired bulk density at elevated temperatures. After cooling, the final phase of production was reached, namely the formatting of the insulator to the desired size (most often 1000 x 500 mm).

Samples of the required dimensions were formatted from the produced materials to determine the required properties.

1) Square samples 300 x 300 mm (determination of thermal insulation properties),
2) Square samples 200 x 200 mm (determination of mechanical, thermal, physical-mechanical and acoustic properties),
3) Circular samples Ø 100 mm and Ø 30 mm (determination of acoustic properties).
4. Methods
A number of laboratory measurements were performed on the above samples to determine the key properties that are essential for the use of acoustic insulation products in building practice. The following properties were determined on the samples:
1) Acoustic properties (ISO 10534-2 and EN ISO 11654),
2) Dynamic stiffness (ISO 9052-1),
3) Thermal insulation properties (EN 12667, (ISO 8301)),
4) Compressibility (EN 12431),
5) Determination of thickness (EN 12431 and EN 823).

5. Results and discussion

5.1. Physical and mechanical properties
The key properties for insulating materials include the determination of thickness (at standard load 50 Pa/samples 1–3/ or 250 Pa /samples 4 and 5/), bulk density and compressibility. The bulk density was given by production, but for the sake of clarity the actual values according to EN 1602 were measured. The thickness of the sample was determined according to EN 12431 and EN 823 and compressibility according to EN 12431. All tests were carried out on samples measuring 200 x 200 mm. The measurement results are shown in the following table [10].

| Table 2. Overview of measured thicknesses, bulk density and compressibility in test samples of acoustic insulation from waste textile. |
| Sample identification | Thickness [mm] | Bulk density [kg/m³] | Compressibility [%] |
|------------------------|---------------|---------------------|---------------------|
| Sample 1               | 42.54         | 112.7               | 13.8                |
| Sample 2               | 52.80         | 98.3                | 18.8                |
| Sample 3               | 84.47         | 56.3                | 40.9                |
| Sample 4               | 15.12         | 218.4               | 8.8                 |
| Sample 5               | 23.41         | 175.6               | 6.6                 |

The highest bulk density was achieved in sample 4 (218.37 kg/m³) thanks to the highest compaction level and the lowest resulting sample thickness. On the other hand, the lowest bulk density had sample 3 (56.31 kg/m³) because of the greatest thickness and therefore low compaction during production. The compressibility corresponds to bulk densities and the lowest was in sample 5 (6.6%) and highest in sample 3 (40.9%).

5.2. Acoustic properties
For insulating materials used in vertical dividing structures (partitions, load-bearing walls), airborne sound insulation and sound absorption in the sound insulation band of 100 to 5000 Hz are an important feature. The single digit value of the sound absorption factor was determined in accordance with ISO 10534-2 in the third octave bands on circular samples with a diameter of 100 and 30 mm. For better clarity and comparison of the individual insulators we determined the weighted sound absorption coefficient according to EN ISO 11654. For materials suitable for use in floor structures, the main criterion is the impact sound insulation of the floor as a whole. In this respect, the dynamic stiffness of the insulating materials according to ISO 9052-1 was determined by the resonance method on samples of 200 x 200 mm [11–13].
Table 3. Overview of measured values of acoustic properties for test specimens of acoustic insulation.

| Sample identification | Dynamic stiffness [MPa/m] | Weighted sound absorption factor [-] |
|-----------------------|---------------------------|-------------------------------------|
| Sample 1              | 6.76                      | 0.55                                |
| Sample 2              | 5.12                      | 0.55                                |
| Sample 3              | 2.92                      | 0.65                                |
| Sample 4              | 19.40                     | 0.30                                |
| Sample 5              | 14.70                     | 0.35                                |

Figure 6. The course of the sound absorption factor for each test specimen in relation to the frequency.

The measured values show the dependence of the acoustic properties on the bulk density of the samples. Samples 4 and 5 with high bulk density reached high dynamic stiffness values (highest sample 4 at 19.4 MPa/m). For samples 1 and 3, the dynamic stiffness values were noticeably lower depending on the bulk density (lowest sample 3 at 2.92 MPa/m). In the area of sound absorption, samples with a lower bulk density (1 to 3) achieved significantly higher values of the weighted sound absorption factor (highest sample 3 with a value of 0.65) than samples 4 and 5 with high density (the lowest sample 4 with a value of 0.3).

5.3. Thermal insulation properties
The thermal insulation properties are very important for both vertical and horizontal structures. This is in particular a structure designed to separate two spaces with a different climatic environment inside. In the case of floor constructions, it is most often a matter of insulating the space from the ground or
unheated space. It is similar in vertical constructions with the issue of insulating the external cladding against the external environment or insulating the space with a different internal environment. Determination of the thermal conductivity coefficient was performed by a stationary plate method on instruments Lambda 2300 and Fox 200 at a temperature gradient of 10 K. The samples for determination of the thermal conductivity coefficient had dimensions 300 x 300 mm or 200 x 200 mm [14–16].

Table 4. Overview of the measured values of the thermal conductivity coefficient.

| Sample identification | Thickness [mm] | Coefficient of thermal conductivity [W/(m.K)] |
|-----------------------|----------------|---------------------------------------------|
| Sample 1              | 42.54          | 0.0396                                      |
| Sample 2              | 52.80          | 0.0405                                      |
| Sample 3              | 84.47          | 0.0434                                      |
| Sample 4              | 15.12          | 0.0419                                      |
| Sample 5              | 23.41          | 0.0421                                      |

Figure 7. Dependence of thermal conductivity of all test samples on bulk density.

The measured thermal conductivity values showed minimal differences between the individual samples. The thermal conductivity values ranged from 0.0396 to 0.0434 W/(m.K). The most favorable thermal conductivity value was measured for sample 1 (0.0396 W/(m.K)). Is possible to see, that optimal interval of density (from point of view of lower thermal conductivity) is between 100–50 kg/m$^3$ (see in figure 7).

When evaluating individual properties, samples 1 to 3 show very good acoustic properties from point of view of airborne sound insulation (high sound absorption coefficient – see in figure 6). These samples seem to be very suitable for use in partitioning vertical constructions to ensure the airborne sound insulation of the structure. For samples 4 and 5, the acoustic properties are slightly worse (but it depends on their low thickness and higher density), but the advantage is minimal compressibility and hence their use in more load-bearing structures (float floor structures). For these insulators, a relatively low value of the thermal conductivity is important to ensure the thermal insulation capacity of acoustic insulation materials. There is very interesting dependence of thermal conductivity on bulk density – see in figure 7. Optimal interval of bulk density was found for test samples higher as usual [3, 5, 7]. It is caused by
composition of test samples and content of crushed edges and chopped filters with lower degree of pulping of textile particles.

**Conclusion**

As part of the development work, the possibility of using textile waste that is difficult to process was verified. These were used filters and edges from the carpet production. By recycling this waste, a secondary raw material was obtained, which was used for the production of medium, higher and high density acoustic insulators for vertical and horizontal construction.

Test samples were used to determine the basic physical-mechanical, acoustic and thermal insulation properties. Based on the determined values it can be said that these materials produced from waste textile (polyester) fibers exhibit very good results in all the identified key characteristics and are comparable to commonly used materials on the construction market.

The greatest advantage of these materials is the processing of waste which is difficult to dispose of, namely textile waste. By using this waste as a primary raw material there is a saving of non-renewable resources and hence the overall reduction of mining and extraction of mineral resources.

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