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INNOVATIVE THERMAL INSULATION MATERIALS BASED ON SHEEP WOOL

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Abstract: *Both nationally and interntionally exists a great concern regarding the valorisation of sheep wool. In this paper it is desired to demonstrate the real qualities of sheep wool as a thermal insulation material. Therefore, here are presented the results of the first phase of the experimental program, where three types of samples were tested having sheep wool as raw material. The samples were tested for apparent density, thermal properties and water absorbtion. For the conducted experiments the equipment from the laboratory of Building Materials was used. All three solutions could represent a potential thermal insulation material considering the value of the thermal conductivity coefficient, however, the most performing does not requires a binder.*

Key words: *sheep wool, thermal conductivity, water absorbtion*

1. Introduction

This paper represents the synthesis of results of the first phase from the experimental program which has the objective of identification of the optimal way in wich sheep wool can be used to obtain a termal insulation material. It is well known the fact that in the agricultural sector anually huge quantities of sheep wool are burned.

Sheep wool is an ecological and renewable raw material. This fact is the main reason why this material was chosen for closer investigation, considering that in recent years particular attention was paid towards sustainability and durability of materials.

The main properties of sheep wool are the following:

- it is easy to handle and does not presents any risks to human health; See: [3], [6].
- improves indoor air quality through absorbtion of formaldehyde; See: [4].
- it is self extinguishing, the fibers does not support combustion due to nitrogen content, but char at high temperatures (580-600*°C*); See: [1], [3].
- it is a hygroscopic (up to 35%) and a permeable material; See: [5], [6].
- absorbtion and desorbtion of humidity does not significantly reduce thermal performance; See: [3].
- it is static resistant and biodegradable. See: [3], [2].

In this paper three different recipes are proposed, three solutions in wich sheep wool can be assembled such that the resulting element should have stable form and dimensions in

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order to determine the apparent density, thermal resistance, thermal conductivity and water absorbtion. One solution does not requires any kind of binder (the fibers are bound by wet felting), but at the other two recipes sheep wool is bonded with hydrated lime or adhezive. Sheep wool was manually washed and treated against insects.

For the realisation of the experimental program the equipment from the laboratory of Building Materials was used, from the Faculty of Civil Engineering of Technical University of Cluj-Napoca. The obtained results are very promising, proving the capability of sheep wool to be a veritable raw materal for obtaining a new termal insulation material.

2. Objectives

This paper's objective is to promote a new material based on sheep wool evaluated from the perspective of performances that are necessary to a thermal insulation material: apparent density, thermal resistance, thermal conductivity and short term water absorbtion.

3. Materials and Methods

3.1. Materials and Preparation of Test Samples

In order to realize the determinations three types of samples based on sheep wool were prepared and studied as follows: wool without binder (Figure 1), wool bonded with hydrated lime (Figure 2) and wool bonded with adhesive (Figure 3).

Fig. 1. *Samples of wool without binder, dimensions 150x150 mm*

Fig. 2. *Sample of wool bonded with hydrated lime, dimensions 150x150x30 mm*

For the conducted determinations the following materials were used: sheep wool, hydrated lime and water-based adhesive. The raw sheep wool, originating from a local shepherd in Sălaj county, before it could be used for determinations it had to be washed and cleaned. The clean wool was treated with boric acid (in proportion of 5% of the wool's weight) in order to protect the material against insects. The hydrated lime was prepared from quicklime. The adhesive used is Novobond BD20K and it is a dispersion of polyvinyl acetate in water.

The processing of wool was carried out manually, the material was washed, carded and felted (where appropriate). First, the raw sheep wool was washed with warm water and soap to eliminate traces of soil, grease and dried plants. The material was washed two times, then rinsed with clean water. During the rinsing process the fibers were treated with boric acid. The second step of processing was carding, which consists in disentangling the fibers with a sharp toothed instrument. After the fibers were carded the material was ready to be used for preparing the samples. Wet felting, which consists in using water and friction to bond the fibers among themselves, was used in case of those samples where binders were not used.

The prepared samples are presented in Table 1.

Prepared and tested samples Table 1

Name of sample	Dimensions [mm]	Notation
Wool without binder	150x150x16	L16_a
	150x150x30	L30_a
	200x200x30	L30_b
	200x200x50	L50_b
Wool bonded with hydrated lime	150x150x30	LV_a
	200x200x30	LV_b
Wool bonded with adhesive	150x150x30	LA_a
	200x200x30	LA_b

To prepare the samples of wool without binder (Figure 1) the method of wet felting was used, which consists in bonding the fibers of wool by applying a solution of warm water and soap over the fibers and moving, rubbing them. Sheep wool fibers in contact with warm water will present a contraction of 40-50*%*, and by rubbing and pressing them these will bond among themselves. For the stability of the final product fibers were arranged after several directions. After obtaining the desired dimensions of samples, these were rinsed with clean water and left to dry at 24*°C*.

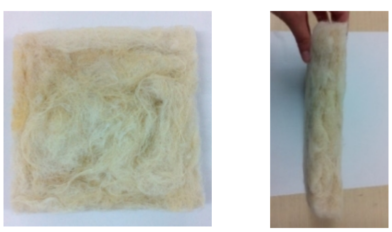


Fig. 3. *Sample of wool bonded with adhesive, dimensions 200x200x30 mm*

To prepare the samples of wool bonded with hydrated lime (Figure 2) wool fibers were manually mixed with lime paste until all the fibers were covered with the binder. Quantities of binders used to prepare the samples are presented in Table 2. After preparing the samples, these were left to dry out for 7 days at 24*°C*.

To prepare the samples of wool bonded with adhesive (Figure 3) wool fibers were manually mixed with the binder. After preparing the samples, these were left to dry out for 7 days at 24*°C*. Quantities of binders used to prepare the samples are presented in Table 2.

3.2. Methodology of the Conducted Laboratory Measurements

On the prepared samples the following determinations were carrie out:

- Apparent density;
- Thermal resistance and thermal conductivity;
- Short term water absorbtion by partial immersion.

Quantities of binder Table 2

Sample	LV_a	LV_b	LA_a	LA_b
Hydrated lime [ml]	500	620	-	-
Adhesive [ml]	-	-	200	250

I. Apparent density

The determination was performed according to SR EN 1602 [9]. The principle of the method consists in calculating the ratio between the sample's mass and volume.

The methodology consists in the following:

- Measuring the linear dimensions of the sample according to SR EN 822 [7] and SR EN 823 [8];
- Determination of sample's mass;
- Determination of apparent density of the sample, ρ_a [kg/m^3], as a ratio between mass, m [kg] and volume, V [m^3] with the formula (1).

$$\rho_a = \frac{m}{V} \tag{1}$$

II. Thermal resistance and thermal conductivity

Fig. 4. *Measuring device for thermal properties, Fox200*

The determination of thermal resistance and thermal conductivity was performed according to SR EN 12667 [11]. The measuring device used for determination was a guarded hot plate apparatus with a single specimen, type FOX200 produced by TA Instruments. (Figure 4). The samples' dimension was 150x150 *mm*. The determination was realized in the laboratory of Building Materials of the Faculty of Civil Engineering. The sample was placed between two plates in the test stack and a temperature gradient was established over the thickness of the material. The plates were positioned automatically by the instrument. In-situ sample thickness is measured with four optical encoders. The measuring device determines implicitly the following properties: thermal resistance and thermal conductivity.

III. Short term water absorbtion by partial immersion

The determination was performed according to SR EN 1609 [10]. The principle of the method consists in placing the sample with it's lower part in contact with water for a period of 24 hours and measuring the sample's mass change. From the two methods indicated by the standard it was used the drain method (method A). The samples' dimension was 200x200 *mm*.

The sample's initial mass, m_0 [kg], was determined by weighing. Then, the sample was placed in an empty reservoir and it was applied enough load to the sample to maintain it partially immersed when water is added to the reservoir. Water was carefully added to the reservoir until the sample's lower part was with 10 *mm* under the water's surface. The water level has been kept constant during the determination. After 24 hours the sample was extracted, it was drained for 10 minutes by placing it on an inclined (by 45°) grid. The sample was again weighed in order to determine it's mass after the test, m_{24} [kg]. The short term water absorbtion by partial immersion, W_p [kg/m^2], was calculated with the formula (2), where A_p [m^2] is the sample's lower part's area.

$$W_p = \frac{m_{24} - m_0}{A_p} \tag{2}$$

4. Results and Discussions

The results of the conducted experiments are presented in Table 3.

I. Apparent density

After analyzing the obtained results it can be seen that for the samples prepared without a binder the apparent density has the lowest values (Figure 5), however, for the samples of wool bonded with hydrated lime the measured value of density cosiderably increased. For the samples prepared from wool bonded with adhesive the value of density is situated between the values obtained for the other two types of samples (Figure 6).

The lowest value of the apparent density was obtained for the sample L30_b, with dimensions of 200x200x30 *mm*, also, the highest value of the apparent density was measured for the sample prepared from wool bonded with hydrated lime, a value of 607.75 *kg/m^3*.

The results of experiments Table 3

Sample	Apparent density [kg/m^3]	Thermal resistance [m^{2}K/W]	Thermal conductivity [W/mK]	Water absorbtion [kg/m^2]
L16_a	97.508	0.486	0.033	-
L30_a	123.88	0.909	0.036	-
LV_a	557.926	0.413	0.075	-
LA_a	233.651	0.619	0.056	-
L30_b	41.64	-	-	3.829
L50_b	50.952	-	-	6.102
LV_b	607.75	-	-	12.33
LA_b	107.463	-	-	5.33

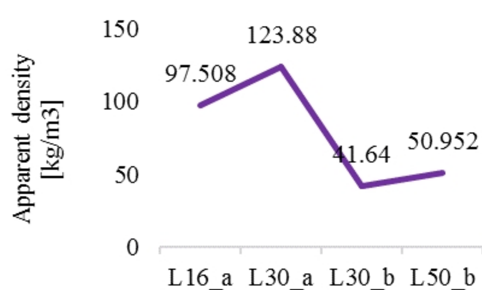


Fig. 5. *Variation of apparent density at samples of wool without binder*

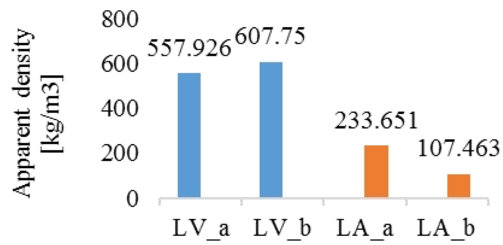


Fig. 6. *Variation of apparent density at samples of wool with binder*

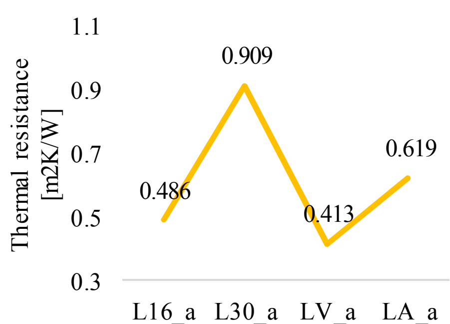
II. Thermal resistance and thermal conductivity

After analyzing the conducted determinations on the proposed samples it can be seen that the sample obtained from wool without binder performs the best regarding the thermal properties compared to the other types of samples.

The values of thermal conductivity for samples made from wool without binder varies between 0.033 and 0.036 *W/mK*. The sample of wool bonded with hydrated lime performs the worst regarding both thermal properties compared to the other samples. Regarding the thermal resistance the highest value was obtained for L30_a (0.909 m^2K/W) and the lowest for LV_a (0.413 m^2K/W). The measured values for LA_a are situated between the values obtained for the other two types of samples (Figure 7).

III. Short term water absorbtion by partial immersion

Regarding the values obtained for water absorbtion it can be observed that for samples made without binder the measured values were the lowest (3.829 kg/m^2 and for the sample realized with hydrated lime this value was the highest (12.33 kg/m^2) as it can be observed in Figure 8.



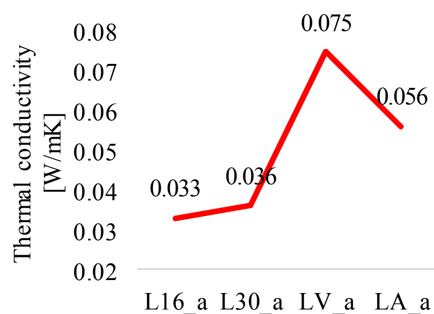


Fig. 7. *Variation of thermal resistance (left) and thermal conductivity (right)*

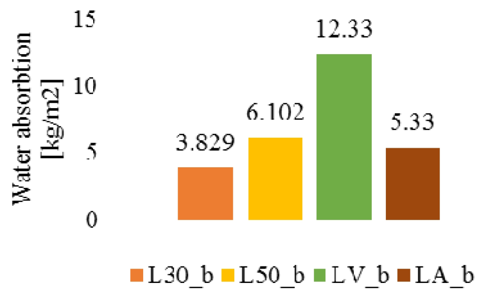


Fig. 8. *Variation of water absorbtion*

After the determination was carried out the samples were examinated visually and the following were observed:

- Samples of wool without binder (L30_b and L50_b) were damp only on their lower part immersed in water, on their upper part they were dry, without signs of degradation;
- Sample of wool bonded with hydrated lime (LV_b) was damp on its upper part too, without signs of degradation;
- Sample of wool bonded with adhesive (LA_b) was damp only on its lower part immersed in water, on its upper part it was dry, but its lower part presented signs of degradation due to the properties of the binder.

5. Conclusions

On the basis of conducted experiments, the following can be stated:

- From the proposed samples, the one prepared from wool without binder has the lowest density (41.64 *kg/m*^{3}), and the highest value was measured for the sample of wool bonded with hydrated lime (607.75 *kg/m*^{3}).
- The lowest values of thermal conductivity were measured for the samples of wool without binder (0.033 *W/mK*, 0.036 *W/mK*), and the highest value was recorded for the sample made with hydrated lime (0.075 *W/mK*). It can be stated that using binders influences in a negative way the thermal properties of the prepared samples.
- Water absorbtion was the highest for the sample made with hydrated lime (12.33 *kg/m*^{2}) and the lowest for the sample of wool without binder (3.829 *kg/m*^{2}). Comparing the values of water absorbtion obtained for the samples of wool without binder, L30_b and L0_b, it can be observed that water absorbtion is proportional with the sample's thickness, meaning that increasing the thickness of the sample results in increasing water absorbtion.

The results of the experimental program presented in this paper highlights the particular qualities of sheep wool from the perspective of a thermal insulation material. By point of view of the apparent density, thermal properties and water absorbtion from the three types of samples studied the most performing is the sample of wool without binder, having an apparent density of 41.64 *kg/m*^{3}, thermal resistance of 0.909 *m*^{2}*K/W*, thermal conductivity of 0.036 *W/mK*, water absorbtion of 3.829 *kg/m*^{2}.

In order to determine the method and place of application of these types of materials further investigations are needed. Obviously, the research will continue, these values being the first results of an experimental program which will develop in the following years.

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