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Characterization of sheep wool panels for room acoustic applications

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Abstract

Given their good thermal insulation properties, sound absorption behaviour, lack of harmful effects on health, and availability in large quantities, natural fibers are becoming a valid option for sound absorption panels in building applications. This paper presents the characterization of sheep wool fibers and panels. The absorption coefficient and the static flow resistivity for samples of different thickness have been measured. It has discussed the possibility of using fabrics obtained with different kinds of woven wool as sound absorbing systems. For this scope, wool tapestries were mounted at a variable distance from the rigid back wall. The high absorption obtained in some frequency bands, depending on the back cavity depth, confirmed the possibility of use wool tapestries for ad-hoc customized acoustic interventions. Finally, this paper discusses the advantages to adopt sheep wool for room acoustic applications.

Keywords: Natural materials, porous materials, sheep wool, sound absorption, airflow resistivity.

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1 Introduction

Sound absorption panels for room acoustic applications are generally composed of synthetic materials, such as glass wool, polyurethane or polyester, which are expensive to produce and are generally based on petrochemicals. The growing awareness towards the environmental implications and health issues associated with these materials has increased the attention towards natural materials [1,2]. These are generally defined according to natural and renewable sources of their constituent materials, the low level of environmental pollution emitted during their production or to their low embodied energy [3].

The basic element for a material to be sound absorbing is its porosity. This may be obtaining according to diverse structure: as cellular, fibrous, and granular [4,5]. Fibrous materials consist of a series of tunnel-like openings that are formed by interstices in material fibers, which may be continuous filaments or discrete elongated pieces. Natural fibers have been receiving increasing attention for acoustic uses [6-10], and a variety of natural fibers for building applications have started being commercialized already.

Natural fibers are competitive materials thanks to their low density, good mechanical properties, easy processing, high stability, occupational health benefits, reduced fogging behavior, high quantity availability, low price, and reduced environmental impacts for their production. They can be vegetable, animal or mineral. While the authors recently worked on vegetable fibers (studying among others kenaf, hemp, cane, coconut, etc.) [6,7], this paper is dedicated to analyze an animal fiber, i.e. sheep wool.

Wool is a renewable and recyclable raw material which is obtained by the shearing of the sheep fleece. It is a textile fiber, environmentally friendly as it does not require energy sources for its production, and clearly it has a natural decomposition cycle. The thermal properties of wool were already known in ancient times when it started to be used as a fabric for clothing purposes. However, only in recent years, given the diffusion of new foams products (i.e. memory foam), there has been little use of the less regular and valuable wool fibers. This means that sheep wool has often no market for applications such as mattresses or cushions, and it is then burnt or buried in the fields. In this scenario, the production wastes of wool have been proposed to creating regenerated wool for civil engineering applications.

Wool is a flame retardant fiber, elastic, breathable, waterproof while with good moisture storage capacity [11,12]. Although, it is not attacked by mold, because it is a protein fiber, it still needs anti-termite treatments to avoid the attack of insects and parasites. The microscopic structure of wool shows that the fiber has keratin flakes that cover the outer surface. Beyond the outer cells form, a regular structure gives a high strength to this fiber. Thanks to the special microstructure, sheep wool is an excellent alternative to mineral fiber for thermal and sound insulation. This paper reports and discussed the measurements of normal sound absorption coefficients using different wool based products.

2 Methodology

The sound absorption coefficient of wool at normal incidence was determined according to the procedure described in the ISO 10534-2 [13]. This method allows to measure normal acoustic parameters by using small samples that are easy to assemble and disassemble. The measurements were carried out using a Kundt's tube with the following features (Fig.1): internal diameter of 10 cm (corresponding to an upper frequency limit of 2000 Hz), length of 56 cm, and two ¼'' microphones, placed at a distance of 5 cm for measurements above 200 Hz.

Known the sample thickness, the sound absorption measurement consisted of determining the complex wave number, and from this to calculate the surface impedance (z_s) and the absorption coefficient (α) using the following expressions:

$$\alpha = 1 - |R|^2 \tag{1}$$

$$R = \frac{z_s - \rho_0 c}{z_s + \rho_0 c} \tag{2}$$

$$z_s = -j z_c \cot(k_c d) \tag{3}$$

where *R* is the sound pressure reflection coefficient, z_c is the characteristic impedance $\rho_0 c$ (Pa·s/m), and *d* is the thickness of the sample (m). To limit the effects due to the irregularities of the samples, four different measurements were performed for each material, every time stirring and inserting the material in the tube. The resulting absorption coefficient values shown in the section 3 are hence the average of the four acquisitions.

Figure 1: Tube of Kundt's fube for normal sound absorption coefficient measurements.

The airflow resistance was measured following the standard ISO 9053 [14]. Measurements were carried out according to the alternate flow method at a frequency of 2 Hz using a device consisting of a cylindrical tube, closed with the sample of the tested material, a piston system, moved by a rotating cam, which creates the alternate air flow inside the tube, and a pressure microphone for the measurement of the pressure disturbance (Fig.2). Measurements were taken with four different cams, corresponding to four air speeds (0.5, 1.0, 2.0, and 4.0 m/s).

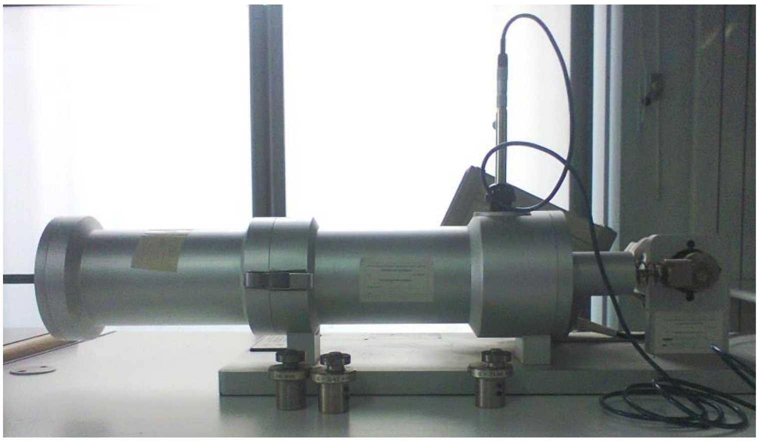

Figure 2: System for the measure of the flow resistivity with the method of the alternate air flow.

3 Tested Materials

Three different materials were tested in this study:

- Sheep wool panels, industrially produced (i.e. a product already on the market and used mainly for thermal applications);

- Raw sheep wool, which has not undergone any processing, and which historically would have been used in cushions and mattresses;

- Woven wool (thin felt) for the realization of tapestries, and tapestries created with 1.5 mm or 2.5 mm diameter wool wires mounted at a variable distance from the rigid termination of the impedance tube.

Figure 3: Photos of the industrial wool panel.

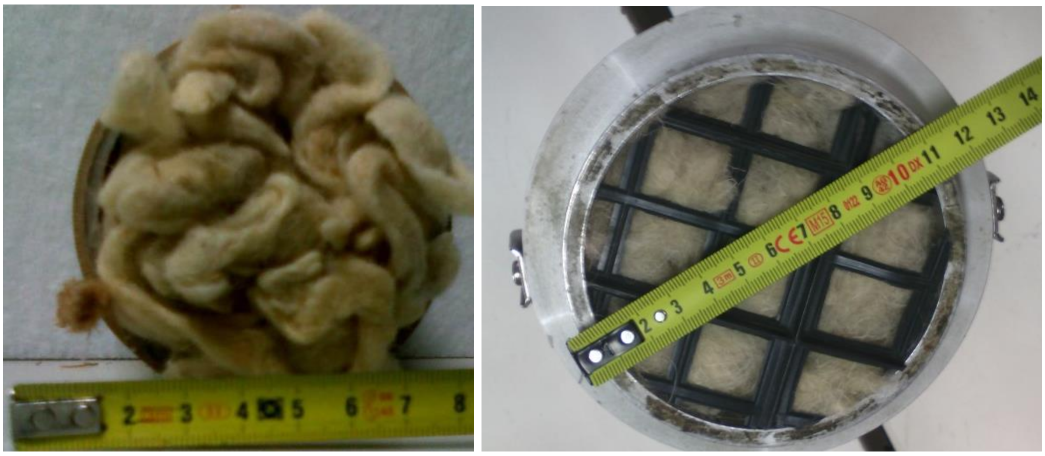

Figure 4: Photos of the raw wool.

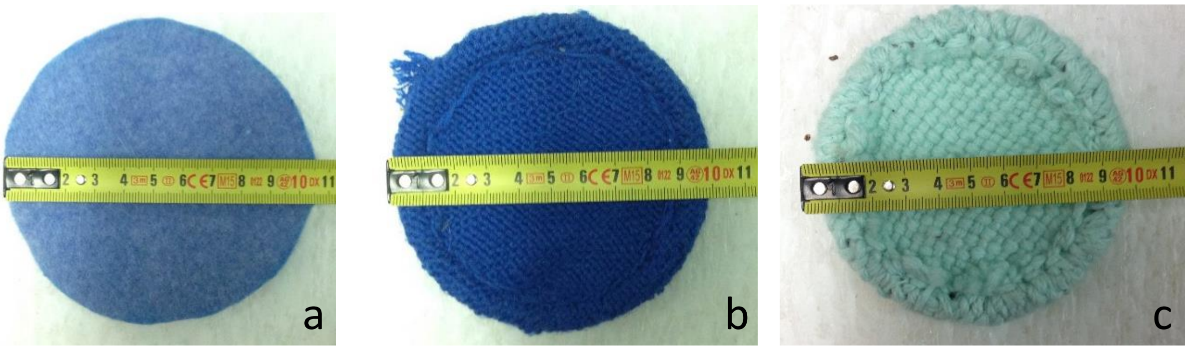

Figure 5: Three wool tissue samples for the realization of tapestries, each one having a thickness around 1 mm: woven wool felt (a), and 1.5 mm (b) or 2.5 mm (c) diameter wool wires.

Table 1 shows the value of the density and flow resistivity of for the industrial and the raw wool. The table does not report the value of the resistivity of the tapestries since the thickness of these specimens was about 1 mm and therefore the flow resistivity was highly variable.

Table 1: Airflow resistivity of wool.

Material	Density, kg/m^3	Flow Resistivity, Rayl/m
Industrial wool	20	3600
Raw wool	40	3500

4 Results

Figure 6 shows the sound absorption coefficient measured at normal incidence for the industrial wool panel for the specimens 5 cm and 10 cm thick. For the thinner sample, the sound absorption increased with frequency, being above 0.5 for the frequency greater than 1000 Hz, with an almost linear behaviour. For the thicker (10 cm) sample, the sound absorption coefficient increases significantly at low frequencies, then it assumes the value close to 0.9 around the frequency of 700 Hz, and finally it decreases slightly, while remaining generally high.

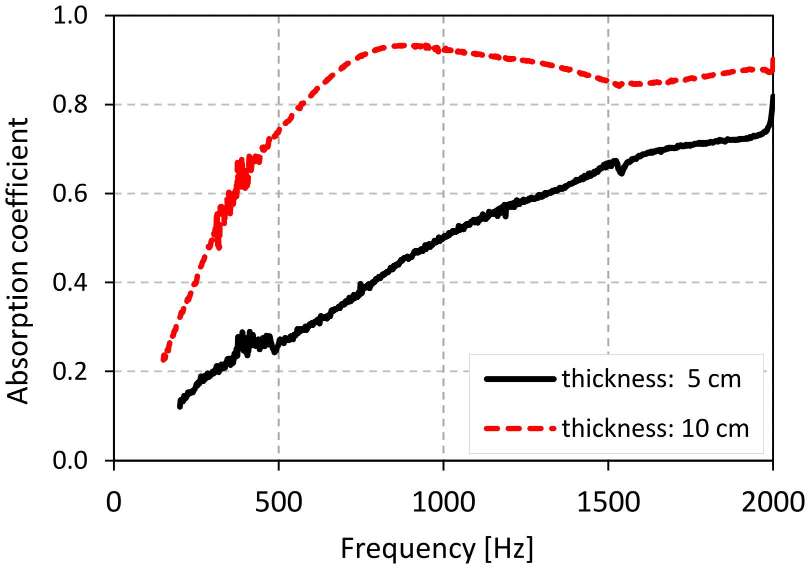

Figure 6: Absorption coefficient for the industrial wool samples with different thickness

Figure 7 shows the sound absorption coefficient measured at normal incidence for the raw wool. For the specimen with a thickness of 5 cm, the value of the absorption coefficient assumes the maximum value equal to 0.8 for frequency above 1000 Hz, while for the thickness of 10 cm, the sound absorption coefficient increases at low frequencies and assumes values close to 1 above 800 Hz, with a generally high absorption.

Table 2 reports the absorption coefficients in one-third octave bands for the different samples.

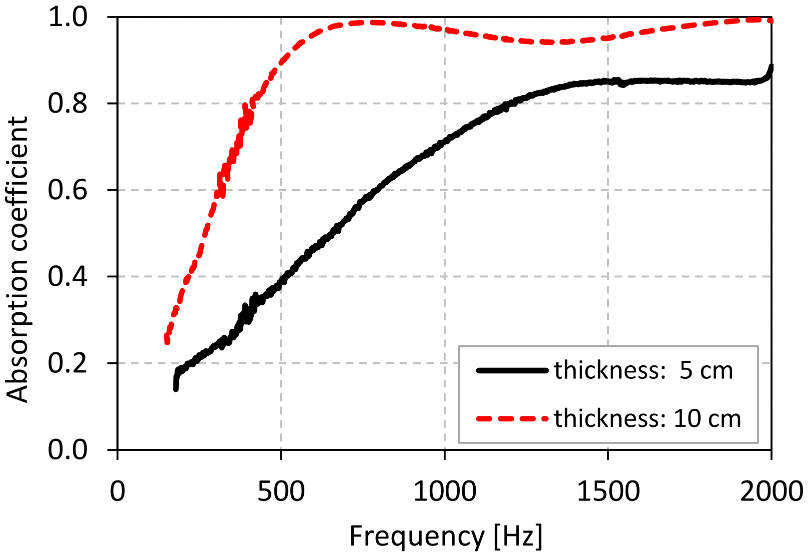

Figure 7: Absorption coefficient for the raw wool samples with different thickness.

Table 2: Sound absorption results in one third octave bands (values in italics are reported although the equipment used for the measurement had less accuracy at those frequencies).

Frequency, Hz	Industrial wool		Raw wool	
	thickness 5 cm	thickness 10 cm	thickness 5 cm	thickness 10 cm
125	*0.10*	*0.20*	*0.12*	*0.22*
160	*0.10*	*0.26*	*0.15*	*0.28*
200	0.13	0.32	0.18	0.37
250	0.17	0.40	0.21	0.45
315	0.21	0.53	0.27	0.70
400	0.26	0.66	0.31	0.76
500	0.28	0.62	0.38	0.89
630	0.31	0.82	0.49	0.97
800	0.41	0.91	0.57	0.98
1000	0.49	0.92	0.70	0.97
1250	0.58	0.90	0.78	0.95
1600	0.66	0.88	0.85	0.95
2000	0.72	0.87	0.72	0.95

The raw wool has a higher value of the absorption coefficient with respect to the industrial wool panel. This is probably due to the presence of more interwoven fibres that allow for greater acoustic absorption. As expected, the values of the sound absorption increased with the thickness, especially in the low frequency range. The results show that sheep wool can be considered a viable substitute to conventional fibres for acoustic applications.

For aesthetic applications, the study looked at specimens of twisted wool threads, and it assessed the properties of wool panels of small thickness and aesthetically valid to be used in the field of correction of acoustic environments [16].

A flexible panel placed at a certain distance from a rear rigid wall and that is excited to vibrate when struck by a sound wave, absorbs a large part of the incoming sound energy [16,17]. Such a system would have a resonant behaviour for which the absorption would be maximum when the incident wave frequency coincides with the resonance frequency of the system, which is determined mainly by the depth of the cavity of air behind the sample (Fig.8). The sound absorption is highly influenced by the distance of the panel from the rear rigid wall, in a way that, the maximum absorption results for a cavity equal to λ / 4 (being λ the sound wavelength). This means that a greater depth of the cavity moves the absorption towards the low frequencies.

Figure 8 shows a schematic drawing of the measurement setup performed with the Kundt's tube creating a back cavity beyond the tested sample. The acoustic measurements of the sound absorption coefficients were made for the layer of textile wool with a back cavity of 3 cm, 5 cm and 10 cm.

Figures from 9 to 11 report the results of these measurements. As expected, with the increase of the cavity behind the specimen within the Kundt's tube, the maximum sound absorption value moved towards the low frequency range.

The fabric mounted on the cavity thickness of 10 cm showed the maximum absorption around the frequency of 800 Hz. In fact, a cavity with a thickness of 10 cm corresponds to the maximum absorption at a wavelength of $\lambda = 0.40$ m, *i.e.* at a frequency of about 850 Hz. When the thickness of the cavity reduces, then the maximum absorption values are shifted towards higher frequencies. For cavity equal to 3 cm and 5 cm, the maximum absorption value resulted to be above 1 kHz. Therefore, the mounted 3 cm or 5 cm distance of woven wool thin panels can be employed for the correction of acoustic environments. For special requirements, if the sound field within the environment is generated from unwanted low-frequency components, these can be absorbed by installing the woven wool panels at a suitable distance from the rear rigid wall.

A further investigation regarded the use of an inverse method to fit a Delany-Bazley modified model to the experimental data. This allowed to obtain best-fit inverse laws for the acoustic impedance and the propagation constant. Details of this numerical approach are reported in [18].

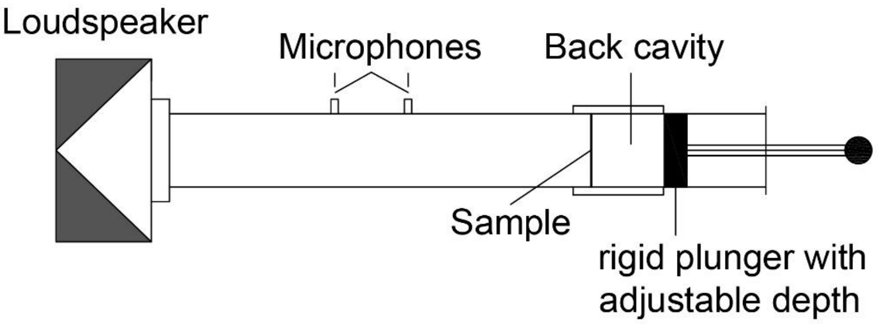

Figure 8: Schematic drawing of the measurement performed with the Kundt's tube using a sample with a back cavity.

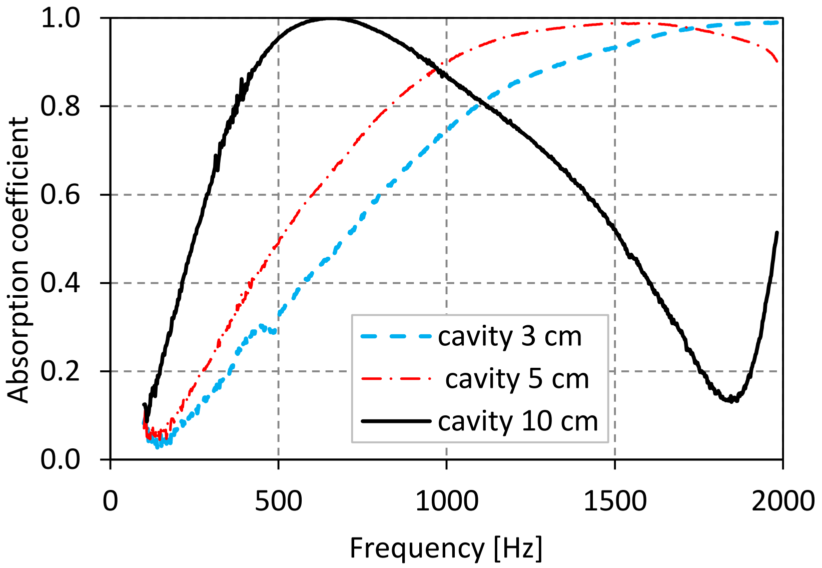

Figure 9: Absorption coefficient for the felt (on cavity) samples on cavities of different thickness.

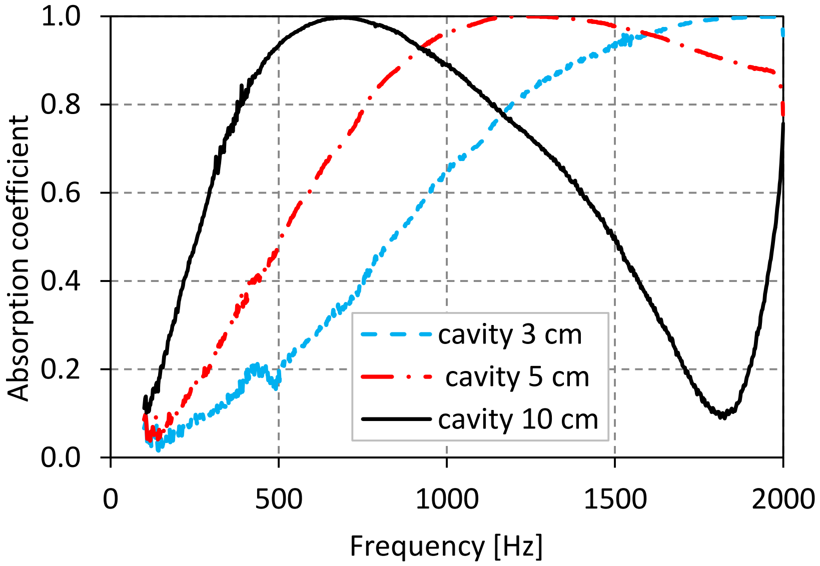

Figure 10: Absorption coefficient for the wool wires with a 1.5mm diameter mounted on cavities of different thickness (sample shown in Fig. 5b).

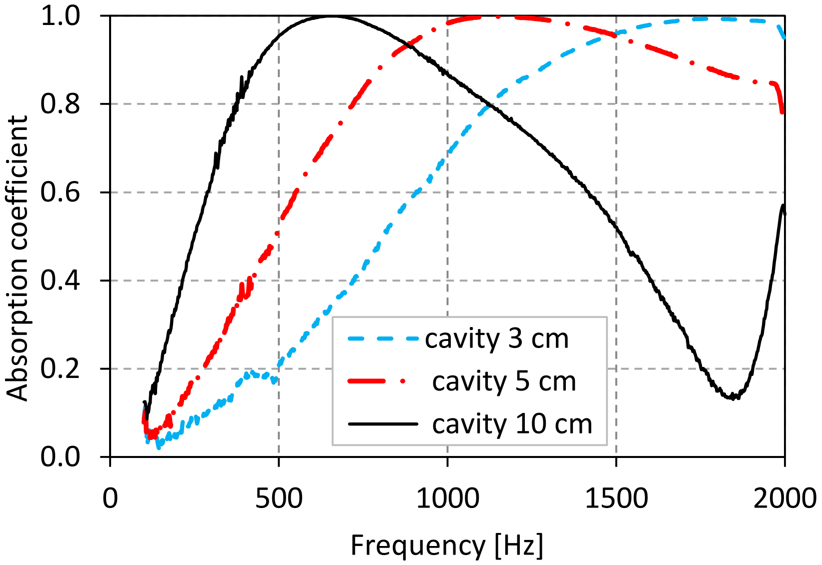

Figure 11: Absorption coefficient for the wool wires with a 2.5mm diameter mounted on cavities of different thickness (sample shown in Fig. 5c).

5 Conclusions

This work has reported the measurements done for different kinds of wool using a Kundt's tube. Results show that wool has good values of sound absorption and can therefore be considered a valid alternative to traditional sound absorbing materials. As expected, with increasing the thickness of the specimens, the sound absorption coefficient increases significantly especially in the low frequency range. The raw wool has higher absorption coefficients than the industrial wool, probably for the presence of more interwoven fibres that allow an increased energy dissipation and thus greater absorption. It has also been discussed the possibility of using fabrics obtained with different kinds of woven wool as sound absorbing systems. The tissues were mounted at a variable distance from the rigid back wall. The high absorption obtained in some frequency bands, depending on the back cavity depth, confirmed the possibility of use wool tapestries for specific ad-hoc customized acoustic corrections too.

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