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Umberto Berardi, Gino Iannace, and Maria Di Gabriele

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Characterization of sheep wool panels for room acoustic applications

Umberto Berardi
Department of Architectural Science, Ryerson University, Toronto, ON, Canada; uberardi@ryerson.ca

Gino Iannace and Maria Di Gabriele
Department of Architecture and Industrial Design, Second University of Naples, Aversa, Italy; Gino.Iannace@unina2.it; maria.Digabriele@unina2.it

Given the good thermal and sound absorption properties, the lack of harmful effects on health, and the availability in large quantities, natural fibers are becoming a valid option for sound absorption panels in building applications. This paper investigates sheep wool fibers and panels. The absorption coefficient and the static flow resistivity for samples of different thickness are measured and discussed. Then, the possibility of using fabrics obtained with different kinds of woven wool as sound absorbing systems is investigated. 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 using wool tapestries for ad-hoc customized acoustic interventions. Finally, this paper discusses the advantages of adopting sheep wool for room acoustic applications.

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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 of several synthetic materials has increased the attention towards natural materials[1,2]. These are generally defined according to the natural and renewable sources of their constituent materials, the low level of environmental pollution emitted during their production or their low embodied energy[3].

The fundamental bulk characteristic for a sound absorbing material is its porosity. A high porosity may be obtaining in different ways so that sound absorbing materials are often categorized according to their structure as cellular, fibrous, and granular[4,5]. Fibrous materials consist of a series of tunnel-like openings that are formed by the interstices among material fibers, which may be continuous filaments or discrete elongated pieces. Given their large availability, natural fibers have been receiving increasing attention for sound absorbing applications[6-10], and a variety of natural materials 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. Natural fibers can be vegetable, animal or mineral. While the authors recently worked on vegetable fibers (e.g. kenaf, hemp, cane, and coconut)[6,7], this paper investigates an animal fiber, i.e. sheep wool.

Wool is a flame retardant fiber, elastic, breathable, waterproof and with a good moisture storage capacity[11,12]. Although it is not attacked by mold because it is a protein fiber, wool 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 the wool fiber. Thanks to the porous fiber structure sheep wool is an excellent alternative to mineral fiber for thermal and sound insulation applications.

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 with 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 foam products (e.g. memory foams), there has been little use of the less regular and inhomogeneous wool fibers. This means that sheep wool has limited demand for applications such as mattresses or cushions, and it is nowadays burnt or buried in the fields.

In this scenario, the production wastes of wool have been proposed to creating regenerated wool for building applications. This paper includes the sound absorption studies about different wool based products.

2. METHODOLOGY

The sound absorption coefficient of wool at normal incidence was determined according to the standard ISO 10534-2[13]. This method allows measuring 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): the internal diameter of 10 cm corresponded to an upper frequency limit of 2000 Hz, while the two ¼’’ microphones placed at a distance of 5 cm corresponded to measurements above 200 Hz.

Given 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 $\rho_0\, c$, and d is the thickness of the sample. To limit the effects of sample irregularities, four different measurements were performed for each material, every time stirring and inserting again the material in the tube. The resulting absorption coefficient values shown in section 3 are the average of the four measurements.

Figure 1: Tube of Kundt’s tube for normal sound absorption coefficient measurements.

The airflow resistance was measured according to the standard ISO 9053[14]. Measurements were compiled following the alternate flow method at a frequency of 2 Hz using a device consisting of a cylindrical tube, a piston system, moved by a rotating cam, which creates the alternate air flow inside the tube (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.

3. TESTED MATERIALS

Three 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), Fig. 3;

- Raw sheep wool, which had not undergone any processing, and which historically would have been used in cushions and mattresses, Fig. 4;
- Woven wool (thin felt), and tapestries created with 1.5 mm or 2.5 mm diameter wool wires. The tapestries were mounted at a variable distance from the rigid termination of the impedance tube, Fig.5.

Table 1 shows the value of the density and the airflow resistivity for the industrial wool and the raw wool. The table does not report the value of the resistivity of the tapestries since the thickness of these specimens was so low that the flow resistivity was highly low and 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 panels 5 cm and 10 cm thick. For the thinner sample, the sound absorption increased with the frequency almost linearly, being above 0.5 for frequencies above 1000 Hz, with an almost linear behavior. For the thicker (10 cm) sample, the sound absorption coefficient increased significantly at low frequencies, then it assumed a value close to 0.9 at the frequency of 700 Hz.

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

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

The raw wool has a higher absorption coefficient than the industrial wool panel. This is probably due to the presence of more interwoven fibers that allow 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 valid substitute to conventional mineral fibers for acoustic applications.

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 study then looked at specimens of twisted wool threads, and it assessed the properties of wool panels of small thickness. The tapestries were considered as an aesthetically valid option in room acoustic interventions.

A flexible panel placed at a certain distance from a rear rigid wall and that is excited to vibrate when hit by a sound wave, absorbs a large part of the incoming sound energy for the porous effect combined with a vibration behavior (as a series of Helmholtz resonators)[15,16]. Such a system would have a resonant behavior. The absorption would be maximum when the incident wave frequency coincides with the resonance frequency of the system, which depends on the depth of the cavity behind the sample. The maximum absorption results for a cavity equal to $l/4$ (being l 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 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 the maximum sound absorption value moved towards lower frequencies. The fabric mounted with a cavity 10 cm thick showed the maximum absorption at frequencies above 800 Hz. In fact, a cavity with a thickness of 10 cm corresponds to the maximum absorption at a wavelength of l= 40 cm, i.e. at a frequency of about 850 Hz. When the thickness of the cavity reduces, then the maximum absorption values shifted towards higher frequencies. For cavities 3 cm and 5 cm thick, the maximum absorption value resulted in being above 1 kHz.

A further investigation regarded the use of an inverse method to fit a Delany-Bazley modified model to the experimental data. This allowed obtaining best-fit inverse laws for the acoustic impedance and the propagation constant. Details of this numerical approach are reported in Berardi and Iannace[17].

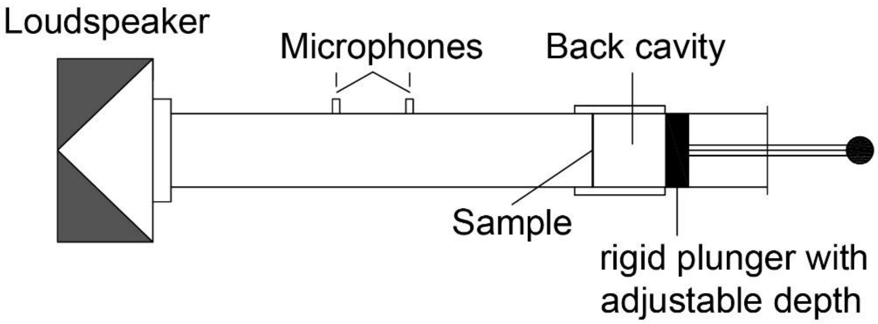

Figure 8: Schematic drawing of the measurement performed with the Kundt's tube mounting the tested sample with a back cavity.

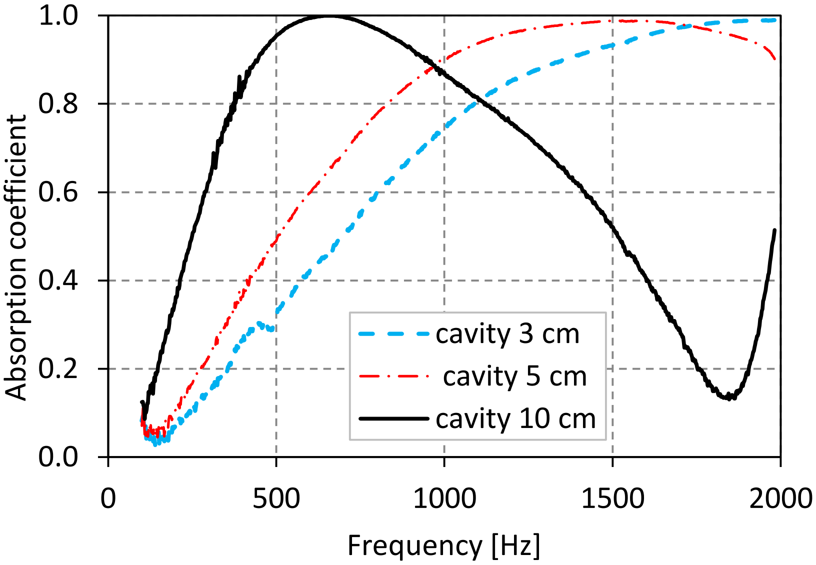

Figure 9: Absorption coefficient for the felt samples on cavities of different thickness (sample shown in Fig. 5a).

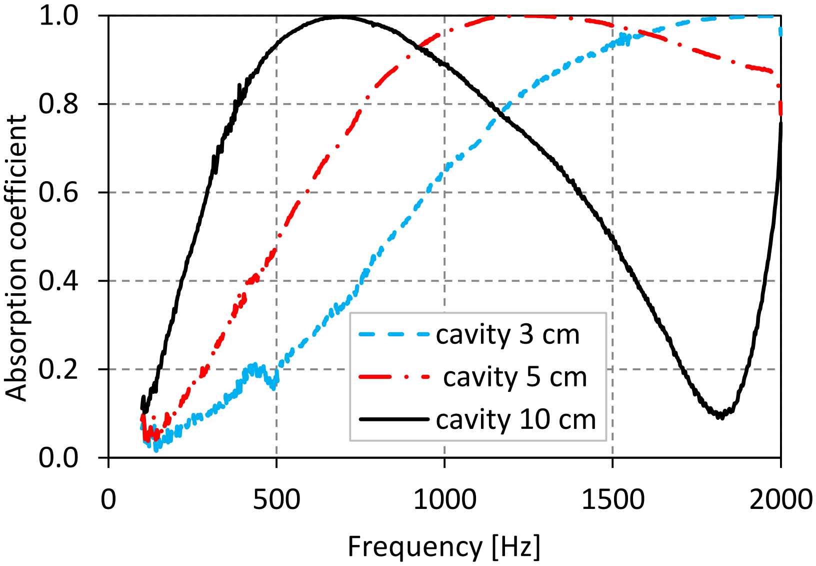

Figure 10: Absorption coefficient for the wool wires with a 1.5mm diameter mounted on cavities of different thickness (sample shown in Fig. 5b).

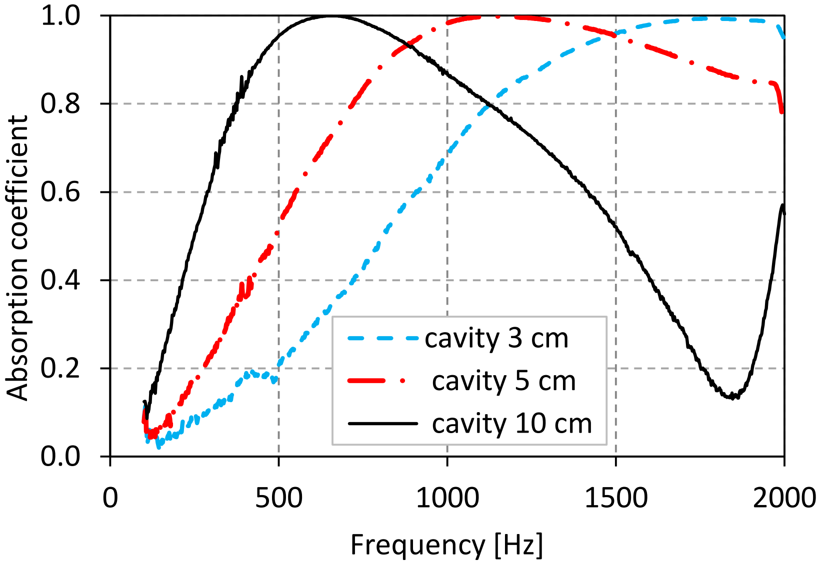

Figure 11: Absorption coefficient for the wool wires with a 2.5mm diameter mounted on cavities of different thickness (sample shown in Fig. 5c).

5. CONCLUSIONS

This work has reported the sound absorption measurements for different kinds of wool fibers. Results show that wool has good sound absorption and can be a valid alternative to traditional mineral 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 given the presence of more interwoven fibers that allow an increased energy dissipation and thus greater absorption. The possibility of using fabrics obtained with different kinds of woven wool as sound absorbing systems has been discussed too. 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 using wool tapestries for ad-hoc customized acoustic corrections.

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