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EVALUATION OF METHODS FOR MODELLING THE IMPACT OF FLAME-RETARDANT TREATMENTS ON THE ACOUSTIC PERFORMANCE OF HEMP WOOLS

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ABSTRACT

Hemp wools are bio-based insulating materials whose applications in green buildings are limited due to their flammable and flame-spreading nature. To overcome this problem while respecting their nature, an environmentally- friendly fire-retardant based on a mix of phosphorus and urea products has been identified. However, experimental characterizations using an impedance tube have shown that this treatment has an impact on the acoustic performance of vegetal wools and therefore on the microstructure of the materials. Until now, this type of impact has not really been studied in the literature. To better understand the effects of fire retardant treatments on the porous and fibrous structure characteristics of hemp wool samples, parameters related to the effects of visco-thermal dissipation such as porosity and airflow resistivity were determined and analyzed. Then, their evolution before and after treatment was evaluated. On the basis of these data, the acoustic absorption of hemp wools could be simulated using equivalent fluid modeling methods (JCAL) and compared with the experimental results for validation. In addition, the variation in fiber radii due to the fire-retardant treatment can be assessed indirectly using micro-macro homogenization methods.

Keywords: *Bio-based materials, Hemp wool, Fireproof treatment, Sound absorption, Homogenization modeling methods.*

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1. INTRODUCTION

On a global scale, according to one of the latest IPCC reports [1], the building field remains one of the main emitters of greenhouse gases (GHG) contributing to climate change. In Europe, with three quarters of the buildings built before 1980, often without thermal regulations [2], this sector has a decisive role to play in achieving European climate objectives. The building sector is also a key element in the fight against noise pollution. According to the EEA [3], in 2019, at least 20% of the European population was exposed to noise levels considered harmful to human health. In this context, acoustic and thermal insulation of both existing and new buildings is therefore a major issue in Europe as on a global scale. In order to respond to these problems, bio-based materials, such as vegetal wools, appear to be the type of insulation that offers the most climate-friendly solution [4, 5]. Indeed, their multifunctional performances, which are directly related to their fibrous and porous microstructure, and their hygroscopic nature contribute greatly to the improvement of acoustic and hygrothermal interior comfort. In addition, they contribute significantly to the storage of atmospheric carbon dioxide [6]. Nevertheless, a number of obstacles still limit their use, such as their flammable and flame-spreading nature [7]. So, to be used in public buildings or as apparent panels such as acoustic baffle or suspended ceiling tile, it is necessary to apply a fireproof treatment. Recent works [8] offer promising ways for treatment with renewable bio-based compounds which are environmentally friendly and compatible with bio-based materials. However, there are very few studies in the literature concerning the impact of such flame retardants on vegetal wools [9]. As a first step, it would seem appropriate to quantify their impact on the acoustic properties at the wool scale. Then, it is therefore essential to better understand the effect of the selected flame retardant on the microstructure of materials. Indeed, acoustic properties, such as the sound absorption of vegetal wools, are directly related to the diameter of the fibers [10].

2. MATERIALS AND METHODS

2.1 Materials

The materials are hemp wools manufactured using a thermobonding process. A reference wool was manufactured without flame retardant treatment. For the other wools, the hemp fibers were treated before manufacture by a fireproof treatment consisting of a mixture of phytic acid and urea. This treatment is applied by spraying with two different formulations of fireproof treatment concentrations, 3% and 5% . An example of treated and untreated samples is shown in Fig. 1. The characteristics of the treated and untreated samples are referenced in Tab. 1. The samples used have thicknesses (e) and apparent densities (ρ_a) of the same order of magnitude in order to compare the sound absorption properties of the samples.

Figure 1. Reference sample on the left, treated sample on the right

Table 1. Characteristics of treated and untreated samples

Sample	Treatment (%)	e (mm)	ρ_a (kg.m-3)
Ref	-	34	63
T3%	3	36	63
T5%	5	35	61

2.2 Methods

2.2.1 Sound absorption

Characterization of sound absorption (α) was carried out using an impedance tube in accordance with standard ISO 10534-2 [11] at normal incidence. The characterization method is based on the use of the 3-microphones method originally developed by Iwase et al. [12] and adapted by Salissou and Panneton [13]. The diameter of the impedance tube (Akustik Forschung - AcoustiTube AFD 1000/1200) used in this work is 100 mm, allowing measurements over a frequency range from 100 to 2000 Hz.

2.2.2 Sound absorption modeling method

The JCAL approach based on the successive works of Johnson [14], Champoux and Allard [15], Lafarge [16] is used to simulate the acoustic performance of the treated and untreated materials. This is a proven semi-phenomenological approach for assessing the effect of the fireproofing treatment on pore geometry. This model is based on the use of 6 input parameters: porosity (ϕ), airflow resistivity (σ), tortuosity (α_∞), viscous characteristic length (Λ), thermal characteristic length (Λ') and static thermal permeability (k'_0). These parameters are characterized by indirect analytical methods presented in Panneton and Olny [17] and Olny and Panneton [18] as a function of the intrinsic parameters, dynamic density and bulk modulus, obtained from impedance tube measurements using the 3-microphone method.

2.2.3 Fiber size modeling method

As well as assessing the impact of fireproofing treatments on the pore network, it would also seem appropriate to evaluate their impact on fiber size. Indeed, the sound absorption properties of vegetal wools are directly related to the size of the fibers [10]. It is therefore possible to use

Tarnow's homogenization method [19], which has already been validated for hemp wools [20]. This method provides analytical relationships between an equivalent fiber radius value (R_f) and acoustic parameters such as porosity (ϕ) and airflow resistivity (σ). The relationship used in this paper, Eqn. (1), corresponds to the configuration of a random fiber distribution and a flow perpendicular to the longitudinal axis of the fibers.

$$R_f = \sqrt{4\mu\frac{(1-\phi)}{\sigma(0.640\ln\left(\frac{1}{1-\phi}\right) - 0.737 + (1-\phi)}} \quad (1)$$

With $\mu = 1.8.10^{-5} Pa.s$ the dynamic viscosity of air.

3. RESULTS AND ANALYSIS

3.1 Sound absorption

As shown in Fig. 2, the experimental results obtained using the impedance tube clearly show a negative impact of fire retardant treatments on the sound absorption coefficient of hemp wool. In addition, there is a correlation between the percentage content of this treatment and the drop in the absorption level and the shift towards higher frequencies.

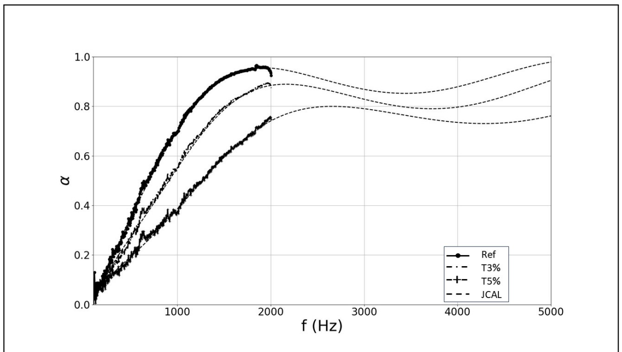

Figure 2. Sound absorption coefficient determined by experimental characterisation and JCAL modelling for reference plant wools, treated at 3% and 5%.

Fig. 2 also illustrates the good correlation between the experimental results and the JCAL modeling. Now, to understand the drop in sound absorption performance, it would seem appropriate to assess the impact of the treatment on the porosity and airflow resistivity of the materials, which are key parameters of the pore network.

3.2 Porosity

There is no significant impact of the fireproof treatment on the porosity of hemp wool. In fact, the porosity of the reference wool was evaluated at 95.8% and at 96.2% for treated wools. This minor difference cannot explain the drop in the sound absorption coefficient observed in Fig. 2. So, it is therefore important to assess the impact of treatment on airflow resistivity.

3.3 Airflow resistivity

The Fig. 3 shows the evolution of airflow resistivity values as a function of treatment concentration. A significant drop can be seen with values of 6257 $Nm^{-4}s$ for the reference hemp wool, 5150 $Nm^{-4}s$ for the wool treated with 3% and 3700 $Nm^{-4}s$ for the wool treated with 5%. Based on this result, we can expect that the fireproof treatment has a coating effect on the fibers, leading to a weakening of the airflow resistivity of the materials.

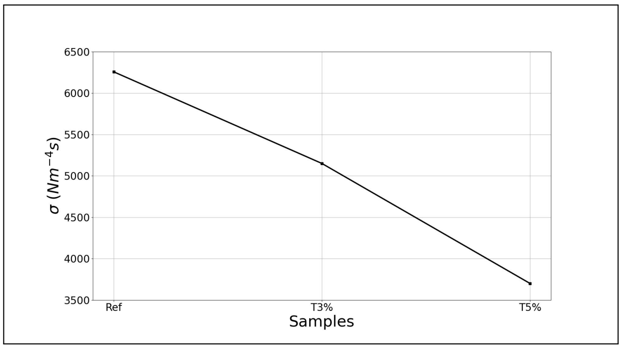

Figure 3. Airflow resistivity for reference hemp wool and treated hemp wools at 3% and 5%.

3.4 Fiber radius

From the above porosity (ϕ) and resistivity (σ) data, it is possible to estimate an effective fiber radius value using Eqn. (1) for each type of treated and untreated hemp wool. The values obtained are indicated in the Tab. 1. The value obtained for untreated hemp wool corresponds to the radius range generally determined from scanning electron microscope image analysis [10]. First of all, we can see higher values for treated wools. This can be explained by a coating effect on the fibers due to the use of the fireproof treatment. In addition, an increase in the value of the effective fiber radii is observed as a function of the concentration of the treatment.

Table 2. Effective fiber radii estimated using the Tarnow modelling method [19]

Sample	$R_f(\mu m)$
Ref	15.5
T3%	16.0
T5%	18.9

4. CONCLUSION

The identification of an effective fireproof treatment that respects the bio-based nature of hemp wool has opened up new prospects for the use of bio-based insulation in green buildings. However, the tests carried out using an impedance tube as part of this work show that the more concentrated the treatment is, the greater the impact both on the level of sound absorption of the wools and on the frequency range, with a shift towards high frequencies. It is shown that the treatment has a minor impact on the porosity of the wools. On the other hand, it has a much more significant effect on airflow resistivity, which helps to explain the impact on acoustic absorption. Tarnow's homogenization method was used to assess the effect of the fireproof treatment on fiber size. A correlation was observed between the concentration of the treatment and the increase in the effective radius of the fibers. This can be explained by a coating effect of the treatment on the fibers. In order to limit these impacts on sound absorption performance, the density of the wools could be considered as a lever for optimization. In addition, it may be appropriate to assess the behavior of materials by applying the treatment by spraying the surface instead of treating all the fibers.

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