International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-2, December 2019

Sound Absorption Measurements of Bio-Sourced Esparto-Fibres : Effect of the Compression

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Abstract: The use of absorbent materials such as fibrous materials is considered as an innovative solution to solve noise problems. The purpose of this research paper is to study the acoustic absorption of a new bio-sourced fibrous material called "Alfa fibers", in order to use it as an absorbent material to reduce reverberation time in the building construction domain (theatre, cinema, conference room, ...). For that, a set of 36 samples was designed and prepared for different thicknesses and different densities in order to evaluate the effect of thickness variation and density variation on sound absorption performance. An experimental study was carried out to measure the sound absorption coefficient at normal incidence, using the ISO 10534-2 standard method known as two-microphone transfer function method. All tests were performed in a Kundt tube with a diameter of 10 cm, in the frequency range (50-1600 Hz). These measurements show that the absorption coefficient can reach a value of 0.9 around 1000 Hz. The experimental results clearly show that sound absorption improves when the thickness of the samples increases, or when the density increases to an optimal value of 300Kg/m^3 from which absorption performance begins to decrease. At low frequencies, sound absorption can be improved by creating an air gap between the sample and the rigid bottom.

Keywords: Alfa-Fibers, Thicknesses, Densities, Acoustic Absorption.

I. INTRODUCTION

In recent years, many researchers have been interested in reducing noise pollution. With scientific research, acoustic insulation and correction are gradually improving. Acoustic correction techniques are generally based on the use of absorbing materials such as porous materials. These materials are widely used in noise control and can be used either in a consolidated state or in bulk. As they can also be found in different morphological forms, three main types are widely cited: fibrous, granular or cellular [1].

Revised Manuscript Received on December 30, 2019.
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As for fibrous materials, the field of their use in acoustics is very wide. Thus, they are found, for example, in the automotive industry or in aeronautics or in building construction [2]. These fibrous materials are distinguished in synthetic or natural form. Synthetic materials such as glass wool, rock wool, polyurethane foam and recycled plastic foams were used as soundproofing materials. And even if these materials are not polluting and do not cause global warming, they are harmful to the health of operators and users [3]. Current trends in scientific research are progressing in the direction of exploring or discovering natural materials as part of acoustic comfort. These materials, which serve as an alternative to synthetic materials, are at the heart of sustainable development In literature, many works on sound absorption characteristics of natural fibrous materials were conducted Bamboo fibers [4], tea fibers [5], coconut fibers [6], sugar cane fibers [7], paddy fibers [8], palm fibers [9], hemp [10], wood waste [11], rice straw [12], alfa or esparto grass [13]. In the literature, the latter material is known by a number of names including alfa, alpha, Stipa tenacissima. Thus, this plant exists all year round in the western Mediterranean region, which is a dry region. And it exists, in large quantities in Morocco especially in the steppes of the eastern region. This plant has a heterogeneous structure, the smallest parts of which are cellulosic filaments or fibrils 2 to 5 mm long and 5 to 10 μm in diameter. The fibrils are connected by hemi-cellulosic fibres with a diameter of approximately 50 μm. Then the fibers are bound by lignin and pectin, which results in bundles of fibers bound together. In this work, the acoustic absorption of this material, in bulk, was studied experimentally. To do this, the sound absorption coefficient was determined using an impedance tube, with a diameter of 10 cm and a length of 100 cm, in a vertical arrangement. This absorption coefficient was used to determine the effect of thickness variation or density variation on the acoustic behaviour of the material alfa. For the study of both effects, a set of 36 samples was manufactured. In the literature several works have been performed to study the effect of the thickness on sound absorption of some natural fibrous or granular materials [13, 14]. Other works concern the effect of density on the sound absorption of porous materials. Indeed, for example Castenède et al. [15], carried out an experimental and theoretical study on the effect of compression on the acoustic absorption of fibrous materials. In the same way, we can cite the experimental work of Khai Hee Or et al. [16].

The authors studied the effect of density on the absorption coefficient of date palm.

II. SAMPLES PREPARATION

For the preparation of the samples, we carried out a series of steps explained below:

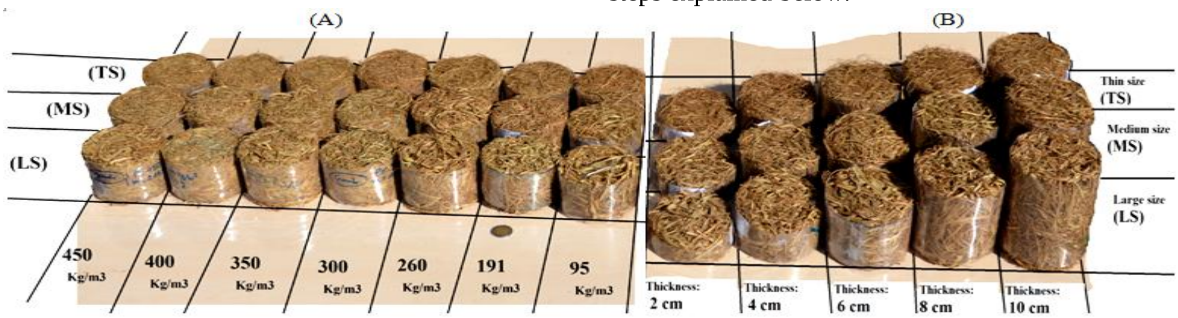

Fig. 1.Prepared samples of esparto-fibers: (A) with one thickness: 6 cm, seven densities: 95 kg/m^3, 191 kg/m^3, 260 kg/m^3, 300 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 450 kg/m^3 and three size: (TS), (MS) & (LS) (B): with different thickness: 2 cm, 4 cm, 6 cm, 8 cm & 10 cm.

A. Sorting phase

The first task involves sorting the esparto-fibers. Thus, in this phase we sorted the particles according to the average of their width to arrive at three classes according to the following configuration: a class of large size whose width varies in the interval [2-5] mm with an average of 3 mm, which is noted in the following by (LS), a second class called medium size, its width varies in the interval [0.5-3.5] mm which gives an average of 2 mm that is noted by (MS) and at the end a third class, called of thin size, whose width of the fibers varies in the interval [0.1-1] mm has an average of 0.5 mm noted by (TS). This sorting was done manually and with the maximum possible precaution. A step that should not be overlooked is the one that preceded the triage. We, therefore , speak of measuring the widths of the fibers by means of a caliper "Fig. 2.D" Thus, a small quantity was taken from each class which was measured with this instrument, then, for each of the classes, its average is noted in a range bounded by a minimum value and a maximum value.

B. Preparation of the containers

In order to have samples in a well-defined concept in terms of symmetrical and regular geometrical shape, we manufactured a set of containers in a cylindrical format of diameter 10 cm. Each of these containers is made using two sheets of flexible plastic and transparent (in format A4). These sheets are glued together to give a single largely sufficient that is joined to the internal surface of a cylindrical gabari hard PVC "Fig. 2.E" and that sticks by its two free ends to obtain a cylindrical container transparent opened by its two bases. Once, the gluing phase is finished, this container is therefore close to filling.

C. Filling of the esparto-fibers particles

All This stage presents, compared to the previous ones, a few difficulties and complications. Thus, the objective was to prepare from these three classes (LS), (MS) and (TS), a set of samples distributed in density and thickness table I. according to the following configuration: seven densities (95 kg/m3, 191 kg/m^3, 260 kg/m^3, 300 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 450 kg/m^3) corresponding to five thicknesses (0.02 m, 0.04 m, 0.06 m, 0.08 m and 0.1 m). For a given sample, the filling step comes after measuring the mass of the esparto-fibers using a precision digital scale (1%).

The following step is the filling of the esparto-fibers in the container so that the volume is filled homogeneously. Thus, to achieve good compaction, two small steel rods similar to the knitting hooks were used. One has a captivating hook in its termination for pulling and tightening and the other has a 'v' shaped end for pushing in the opposite direction as it is present "Fig. 2.E " This operation was carried out during the entire filling process. In addition, another complementary technique is used for large densities higher than 191 kg / m3. We are talking, therefore, about mechanical compaction, which is provided by a manual compression system. This system has been specifically designed and manufactured for this purpose in the research laboratory. This is a manual compression tool with a threaded rod "Fig. 2.C"

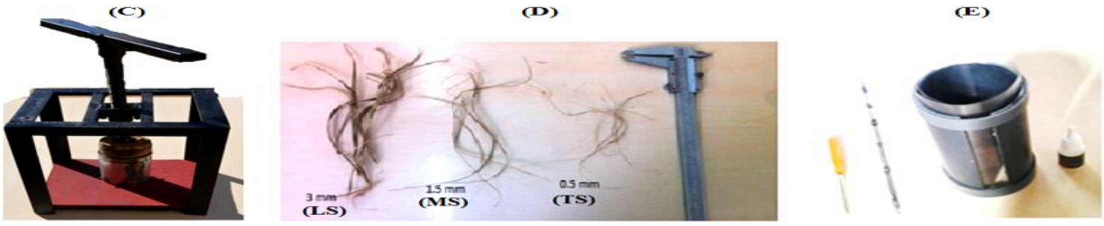

Fig. 2. The tools used for Samples preparation: compression tool(C), different size of esparto-fibers measured by a Calliper. (D), steel rods and Gabari (E).

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Table- I: Distributions of Sample Numbers by Thickness, Size and Density

Classes	Average width (mm)	Density (Kg/m^3)	Thickness (cm)					Number of samples for each thickness
			2	4	6	8	10	
(TS)	0.5	95	-	-	1	-	-	1
		191	1	1	2	1	1	6
		260	-	-	1	-	-	1
		300	-	-	1	-	-	1
		350	-	-	1	-	-	1
		400	-	-	1	-	-	1
		450	-	-	1	-	-	1
(MS)	1.5	95	-	-	1	-	-	1
		191	1	1	2	1	1	6
		260	-	-	1	-	-	1
		300	-	-	1	-	-	1
		350	-	-	1	-	-	1
		400	-	-	1	-	-	1
		450	-	-	1	-	-	1
(LS)	3	95	-	-	1	-	-	1
		191	1	1	2	1	1	6
		260	-	-	1	-	-	1
		300	-	-	1	-	-	1
		350	-	-	1	-	-	1
		400	-	-	1	-	-	1
		450	-	-	1	-	-	1
Number of samples for each density			3	3	9	3	3	Total number of samples is: 36

III. EXPERIMENTAL SETUP

Once the sample preparation phase is completed. The sound absorption coefficient is measured at normal incidence. Thus, in this work that was carried out at the "University Center for Acoustics and Thermal Research" within the Higher School of Technology of SALE, we have a B&K-type of kundt tube equipped with two high sensitivity microphones and a loudspeaker, a white noise generator, a multi-channel data acquisition card and a computer equipped with acoustic data processing software. The Kundt tube or impedance tube used, which has a diameter of 10 cm, is arranged vertically according to the two-microphone method of ISO 10534-2: 2001 [17] "Fig. 3" The frequency domain in which the experimental manipulations were performed is bounded by the two cutoff frequencies of the kundt tube used at 50 Hz and 1600 Hz.

A. Transfer function and Absorption coefficient

In the acoustic impedance tube and according to the chosen frequency range where the plane wave hypothesis is verified, the sound pressure can be written in this way:

$$P = P_i + P_r \qquad (1)$$

Where, p_i is the pressure incident and p_r the pressure reflected.

$$p = p_0 e^{j(\omega t - k_0 x)} + R p_0 e^{j(\omega t + k_0 x)} \qquad (2)$$

p_0 is the amplitude of the incident pressure ω the pulsation. k_0 is the wave number and R the reflection coefficient Under the condition of the termination backing the sample is a rigid termination, One can determine the absorption coefficient of a material through the pressure measurements in two positions p1 and p2 located upstream of the sample. The experimental setup is illustrated in "Fig. 3".

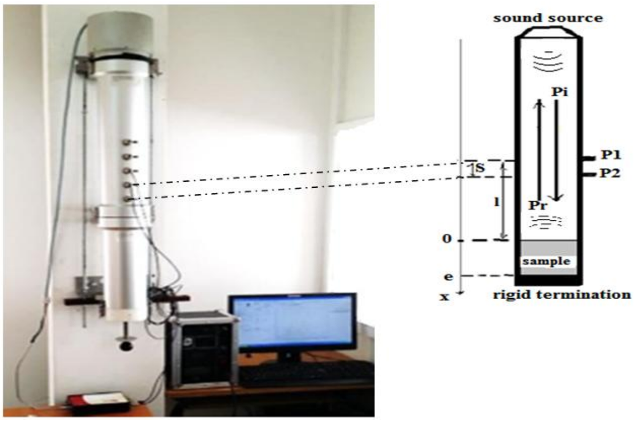

Fig. 3.Experimental Setup

The transfer function between position 1 and position 2 is then written:

$$H_{12} = \frac{P2}{P1} = \frac{p_0 e^{j(\omega t + k_0(l-s))} + R p_0 e^{j(\omega t - k_0 l)}}{p_0 e^{j(\omega t + k_0 l)} + R p_0 e^{j(\omega t - k_0(l-s))}} \qquad (3)$$

The reflection coefficient is written by:

$$R = \frac{H_{12} - e^{-jk_0 s}}{e^{-jk_0 s} - H_{12}} e^{2jk_0 l} \qquad (4)$$

With l: the distance between the microphone of position 1 and the surface of the sample.

S: the distance between the two microphones.

Surface impedance Zs, defined as the ratio of sound pressure to velocity amplitude at the surface of the sample exposed to acoustic waves, can be expressed as a function of the reflection coefficient R by the relation

$$Z_s = Z_0 \frac{1+R}{1-R} \quad (5)$$

IV. RESULTS AND DISCUTION

A. Effect of thickness

First, we measured the sound absorption coefficient for five thicknesses (20mm, 40mm, 60mm, 60mm, 80mm and 100mm) to see the effect of thickness variation on the sound absorption of the material studied.

"Fig. 4" shows the influence of thickness variation on the sound absorption behavior of this material. The results show that as soon as the thickness increases, the sound absorption of low frequencies is improved. The increase in sample thickness results in a translation of the resonance frequency in the direction of the low frequencies. The absorption coefficient reaches 0.93 in the frequency 710 Hz for the thickness 100 mm. This effect of variation of the thickness on sound absorption is not limited only to fibrous materials, but it is also valid for other porous materials. Thus, for the case of granular materials the same behavior can be observed for perlite, vermiculite, cork and glass beads [14]

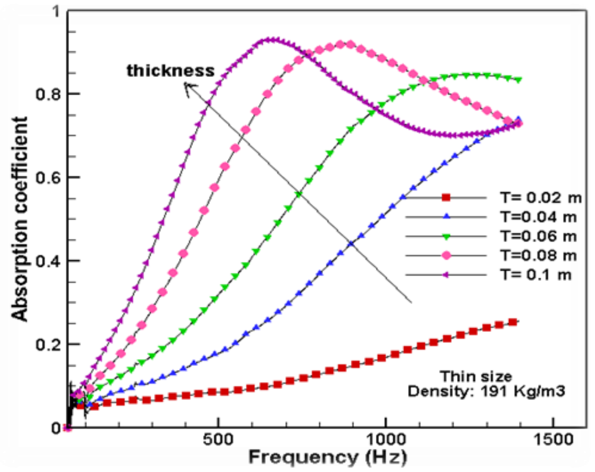

Fig. 4.Effect of thickness variation on the acoustic absorption of esparto-fibers for the class (thin size), the density 191 kg/m^3 and the different thickness:T = 0.02m, T =0.04 m, T =0.06 m, T =0.08 m, T =0.1m

B. Effect of density

The three figures below Fig. 5, Fig. 6 and Fig. 7 correspond to the size classes (TS), (MS) and (LS) respectively. These figures show an overlap of curves characterized by different densities: 95 kg/m3, 191 kg/m^3, 260 kg/m^3, 300 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 450 kg/m^3 . The samples are manufactured in the same volume but it is the mass that varies. The thickness is fixed at 6 cm.

Knowing that density D is defined as the ratio of the mass of the sample to its volume, which is the product of the thickness and the surface area of the section.

The work of Castagnède et al. [15] explored the compression effect on the acoustic absorption of fibrous materials. To vary the density, the authors acted on the thickness to vary the density. But in our case it is the mass that we have varied for the density variation

In these three figures, for frequencies below 450 Hz, it can be seen that when changing from a density to a higher density, the curve corresponding to the higher is placed above the one that is less high. This is in agreement with the work of Castagnède et al. [15]. Indeed, the authors showed the same phenomenon when the sample thickness decreases, i.e. the density increases. It can be said that the increase in density in this frequency area favours the absorption of low frequencies. For the frequency range (450, 1000)Hz, in the three figures Fig. 5, Fig. 6 and Fig. 7, there is an increasing in the absorption coefficient according to the density until the density 300 kg/m^3 where the absorption coefficient start to regress. The phenomenon can be explained by the modification in the physical parameters of the material such as the porosity, the air resistivity, the tortuosity and characteristic viscous and thermal lengths.

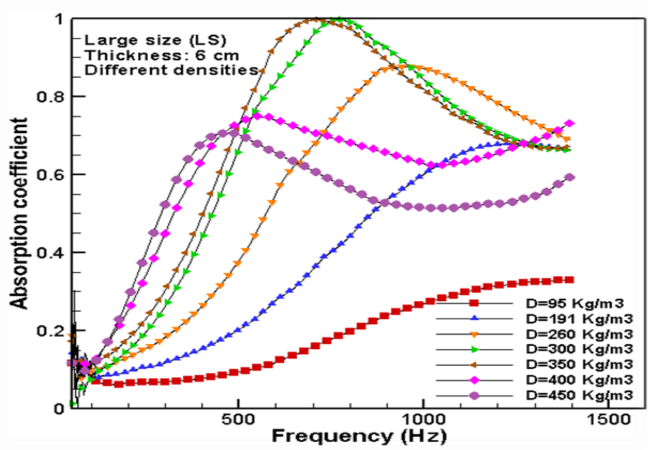

Fig. 5.Sound absorption curve for large-size (LS) of the esparto-fibers material with seven densities

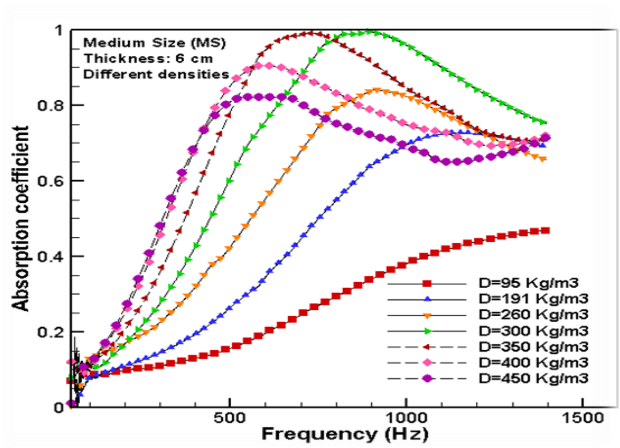

Fig. 6.Sound absorption curves for medium-size (MS) of the esparto-fibers material with seven densities.

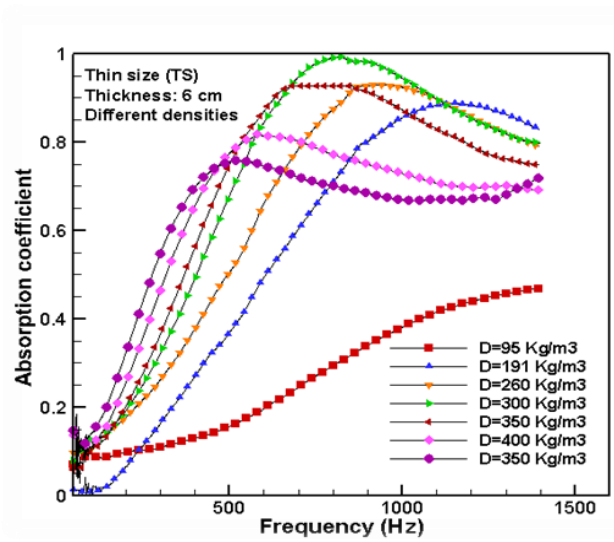

Fig. 7.Sound absorption curves for Thin-size (TS) of the esparto-fibers material with seven densities.

V. CONCLUSION

In this work measurements of the sound absorption of loose alfa-fibers was achieved in the frequency range (50-1600 Hz) for different thicknesses, fiber sizes and densities. First, the measurement was carried out for two purposes: the thickness effect and the density effect. This study showed that the increase in thickness has the effect of moving the curves towards the low frequencies, i.e. the absorption of the low frequencies is promoted by increasing the thickness. For the same class and thickness, the increase in density has the effect of moving the first resonance frequency to the low frequencies with a gradual increase in the absorption coefficient which reaches the value of 1 for the density of 300kg / m3. From this density the first resonant frequency continues to evolve towards low frequencies put with a gradual decrease of the absorption coefficient. It seems that the value of 300kg / m3 constitutes a transition density for which the structure of the material skeleton has different influences on the absorption processes. These observations are currently undergoing corroboration by inverse technical and measurements of the non-acoustical parameter of the samples such as the porosity the tortuosity, the air resistance and the characteristic viscous and thermal lengths.

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