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Effect of the variables associated with the microcapsules on sound absorption after their application to textile fabrics

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ABSTRACT

The aim of this study is to analyze the influence of microcapsules on the sound absorption after their adhesion to textile cotton fabrics by impregnation technique. In order to determine the acoustic properties of the new sound absorbing materials, classical characterization techniques of the materials are used: the sound absorption coefficient at normal incidence and the air flow resistance based on Ingard&Dear work. A comparative analysis between the acoustic absorption of cotton fabrics (CO) with the same yarn density and different microcapsule concentration and different yarn densities with the same doping percentage is presented.

Keywords: sound absorption, cotton fabrics, microcapsules
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1. INTRODUCTION

Noise pollution is the presence of any kind of noise or vibration that may cause nuisance, harm or risk on people and the environment [1].

Last years, according to the World Health Organization (WHO) [2], noise pollution has become very important due to the detection of psychological and physiological problems on the population provoked by the excess of sound produced of human activities [3]. A few examples of these problems are tachycardia, pupil dilation, fatigue, hearing loss, stress, headache, less blood supply, decreased working capacity and cardiovascular disorders.

Traditionally, with the aim of reducing noise pollution, absorbent materials such as glass wool or mineral wool were used, which are difficult to recycle [4]. At present, this trend is changing and proof of this are the European Research and Innovation programs (H2020 and H2030). There is a need to investigate new and innovative absorbent materials to replace other materials that are aggressive with the natural environment [5]. Natural fibers from recycled materials are more suitable than petroleum derivatives, which can become acoustic materials applicable to environment, construction, transport, industry and other areas [6−9].

In the textile industry, new acoustic fabrics were made from the remains of other materials and other manufacturing processes and it is a good idea to reuse such wastes to manufacture new fabrics, in combination with natural fibers or other types of fibers. For that purpose, different techniques such as knitting, weaving or nonwoven are used [10−11]. The acoustic properties of fabrics may vary depending on the method of preparation, their nature, fibers and pore treatment, yarn density and humidity conditions.

Textile fabrics have been widely used in public spaces [12−13], such as museums, theaters, opera houses and other spaces with the objective of providing sound quality by using carpets or curtains. At present, the consumption of textile fabrics is increasing rapidly throughout the world due to the appearance of new areas of application in construction, transport and industry [14].

The most commonly used textiles for acoustic purposes are nonwovens and due to its lack of aesthetic appeal, these textiles are covered with woven fabrics in order to produce a pleasant appearance [15]. In 1990, Shoshani showed in [16] the effect of the intrinsic parameters (some of them are fiber content, the air gap behind the fabric and yarn count) of woven fabrics on the sound absorption coefficient. Na et al. (2007) investigated the sound absorption properties of micro-fiber fabrics [17]. With the same thickness, micro-fiber fabrics have better sound performance than traditional textile fabrics due to its greater surface area, resulting in higher airflow resistance. In 2012, Chevillotte studies [18] a multilayer by a downstream porous media and a resistive layer for increasing the sound absorption performance. Recently, Segura-Alcaraz et al. researched [19] the best combination fabric-nonwoven textiles and the results presented showed a good acoustic behavior. Both, thermal effects of the nonwoven and resonant effects of the fabric cause a significant effect of the sound absorption coefficient.

Due to the rapid evolution in textile engineering, Nelson G. in 1991 considered the use of microcapsules (MICs) in textile fabrics for the first time [20]. With MICs is possible to confer new properties to textile fibers with respect to traditional nonwoven textiles [21−22].

MICs are micrometric particles comprised of one or more active ingredients that consist of a membrane (outer layer) that encompasses the active compound in the nucleus [23]. Microencapsulation is used to alter the physical properties of the volatile substance used in order to make it more manageable and to protect it from multiple external factors such as sunlight, evaporation, humidity, alkalinity, unwanted rubbing action or the combination between them [24]. The most known industrial methods for adhering microcapsules onto textile fabrics are bath exhaust, padding, spraying or coating.

Since the introduction of microencapsulation in the textile sector many modern applications were developed. Some examples are uniforms, gloves and military tents with microencapsulated insecticide, fabrics with durable fragrances, T-shirts with microcapsules to absorb UV rays, ski suits, clothing with thermo-changeable dyes and thermal regulation of car seats [25−26].

Unlike microspheres, the MICs are particles composed of one or more active agents in their interior, whose membrane (external part) protects the nucleus (active principle). In this work, we evaluate the influence of doping with MICs by measuring the sound absorption coefficients with an impedance tube and using an air cavity between fabric sample and the rigid end. On the one hand, a comparative analysis of cotton fabrics (CO) with the same yarn density and with different content of microcapsules is presented. On the other, the effect of the different yarn densities with the same doping percentage are also studied. Doping fabrics with MICs is shown to be an effective method for the control their sound absorption.

2. MATERIALS AND METHODS

2.1 Materials

Cotton (CO) has been widely used in the textile industry for its biodegradable natural fiber, permeability, softness, comfort and high wettability [27]. In this study, CO fabric samples were obtained with a chemically and optically bleached. Two cotton fabrics from the same family but different grammage, dyeing and yarn density have been analyzed. It is a twill weaved fabric with 115 g/m^2 and 210 g/m^2 (see Figure 1).

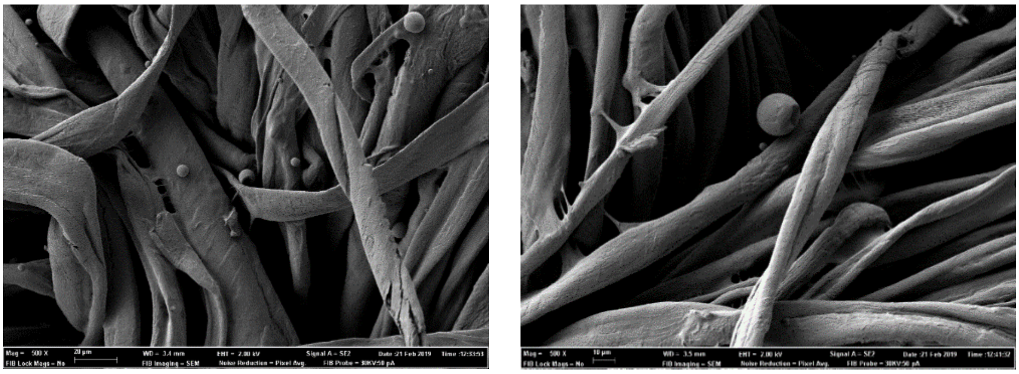
Figure 1. *Textile fabrics used in this study. Left: CO fabric with a yarn density of 115 g/m^2; Right: CO fabric with a yarn density of 210 g/m^2.*

2.2 Adhering microcapsules onto fabrics

During the application process, the shape, size, durability, permeability and wall properties of the MICs must be considered. The padding is an impregnation technique to adhere MICs onto the textile fabrics surface, which consists of a rapid immersion process of the textile sample and two squeezing rolls press the liquid form both sides in the treatment bath, to force the liquid to pass through the fibers. The padding process was made with horizontal fulard TEPA. The fulard speed and pressure were regulated in order to obtain a pick up [28] around 80% (percentage of bath absorbed by the textile fabric).

The MICs used have as active principle lavender essential oil fragrance, which were supplied by InnovaTec S&C S. L. and its size varies from 3 µm to 6 µm. CO samples were prepared in a treatment bath depending on the amount of MICs: 5 g/l, 15 g/l, and 25 g/l. To complete the adhesion process between fibers and MICs, the CO samples was dried in a horizontal infrared dryer during 180s at a temperature of 105ºC.

MICs due to its micrometric size are imperceptible to the human eye. In order to observe, with high resolution, the surface of the CO fabric, Field Emission Scanning Electron Microscope (FESEM) model ULTRA 55 of the ZEISS brand was used. With this technique, it is possible to visualize the shape of the membrane of each microcapsule (smooth or rough), their structure, their size and their location [29−30]. In this study, CO samples were examined with suitable accelerating voltage of 2 kV and 500 magnifications (see Figure 2).



(a) *MICs content: 5 g/l* ***(b)*** *MICs content: 10 g/l*

Figure 2. *FESEM micrographs of cotton fabrics with a density of 115* g/m^2 *and 500 magnifications. (a) Sample surface of CO fabric doped with a MICs content of 5 g/l; (b) Sample surface of CO fabric doped with a MICs content of 10 g/l.*

2.3 Experimental setup

The CO samples measurement campaign was carried out in the Higher Polytechnic School of Gandia at the Universitat Politècnica de València. For the acoustic characterization, the methods used in this work are, on the one hand, the standard ISO 10534−2:1998 [31], in order to determine the normal incidence sound absorption coefficient; on the other hand, the recommendations proposed by Ingard and Dear in [32] to measure specific air flow resistance.

According to the standard procedure detailed in [31], a methacrylate rigid, smooth, transparent and airtight impedance tube of circular cross section, two fixed microphone positions (spaced a distance s) and a digital signal analysis system (Pulse LabShop software version 22.2.0.197) have been used.

The impedance tube used has an internal diameter of 4 cm. At one end of the tube, a loudspeaker (Beyma CP−800Ti) with a random white noise signal emits plane waves; at the other end, an air cavity of 10 cm is mounted (see Figure 3). The pressure signal in each position is recorded using two 4190 (1/2-inch) free-field Brüel & Kjaer microphones and these must be calibrated before starting measurements considering a pressure level of 94.0 dB at 1 kHz as reference. The usable frequency range is limited by the distance between microphones, by the precision of the signal processing equipment and by the tube's inner diameter according to [31]. Thus, the frequency range of measures is from 100 Hz to 3150 Hz and $\lambda \gg 1.7D$ in order to ensure incident plane waves. In Figure 4(a) the experimental setup used in this test can been seen in considerable detail.

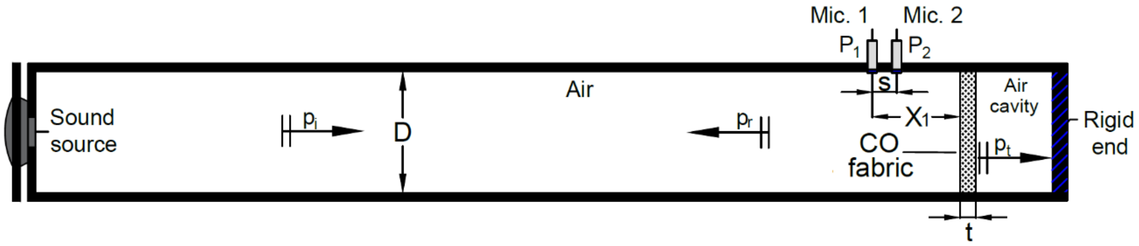
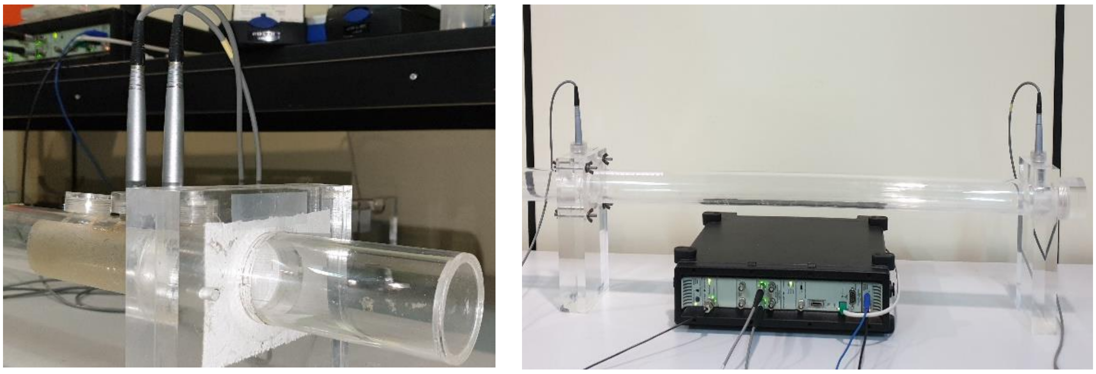


Figure 3. *Schematic diagram of the impedance tube with an air cavity of 10 cm for measuring the normal incidence sound absorption coefficient in accordance with the ISO 10534-2:1998. D is the tube's inner diameter;* p_i *is the sound pressure of the incident wave;* p_r *is the sound pressure of the reflected wave;* p_t *is the sound pressure of the transmitted wave; t is the sample thickness.*



(a) *Air cavity method* ***(b)*** *Ingard&Dear method*

Figure 4. *Experimental measurement of the cotton samples. (a) Measurement of normal incidence sound absorption coefficient with an air cavity; (b) Measurement of air flow resistance using the Ingard and Dear method.*

The transfer function from microphone position one to two, H_{12}, can be defined as the complex ratio between the pressures registered in these positions

$$H_{12} = \frac{p_2(\omega)}{p_1(\omega)} = \frac{e^{-jkx_2} + re^{jkx_2}}{e^{-jkx_1} + re^{jkx_1}}, \qquad (1)$$

where *r* is the reflection coefficient, p_1 and p_2 are the acoustic pressures recorded by each microphone, *k* is the wave number, x_1 and x_2 are the distances between both microphones with respect to the CO sample.

The complex reflection coefficient (r) is obtained from the Equation 1 and it can be observed as follows

$$r = \frac{H_{12}-H_I}{H_R-H_{12}} e^{2jk_0x_1} , \tag{2}$$

where $H_I = e^{jks}$ is the transfer function of the incident wave, *s* is the distance between both microphones (s = 3.2 cm), $H_R = e^{-jks}$ is the transfer function of the reflected wave, k_0 is the wave number, $j=\sqrt{-1}$ and x_1 is the distance between the sample and the microphone placed further away from it.

The specific acoustic impedance (Z) is calculated from the Equation 2 as follows

$$Z/\rho c_0 = R/\rho c_0 + j\, X/\rho c_0 = (1+r)/(1-r), \tag{3}$$

where R is the real part, X is the imaginary part, ρ is the average air density and c_0 is the speed of sound in the tube.

On the one hand, the normal incidence sound absorption coefficient (α_n), which represents the quotient between the acoustic energy absorbed by the surface of the sample and the incident acoustic energy for an acoustic plane wave at normal incidence can be obtained as follows

$$\alpha_n = 1 - |r|^2. \tag{4}$$

On the other hand, air flow resistance is also measured in order to evaluate the difficulty of an air stream to flow through the CO fabric per unit thickness (t) (see Figure 4(b)). The experimental setup is based on the indirect method proposed by Ingard&Dear that allows to obtain the value of the specific air flow resistance under certain limitations that do not depend on frequency specified in [32].

In this method, the sound source excite the tube with a broadband stationary random noise in order to produce an odd number of quarter wavelengths of the sound throughout the distance between the CO sample and the rigid end denoted by $L+t$.

It is possible to obtain the air flow resistance (σ) finding the minimum of the imaginary part of the pressure ratio p_1/p_2. For all CO fabrics, the minima are observed at 100Hz, 300Hz, 500Hz, 700Hz and 900Hz, approximately. Thus, it is possible to calculate the average values of the air flow resistivity (air flow resistance divided by the sample thickness *t*) using the absolute value of the imaginary part of the transfer function between the microphone signals as follows

$$\sigma \approx \left(\frac{\rho c_0}{t}\right) \left|\mathrm{Im}\left(\frac{1}{H_{12}}\right)\right| . \tag{5}$$

3. RESULTS AND DISCUSSION

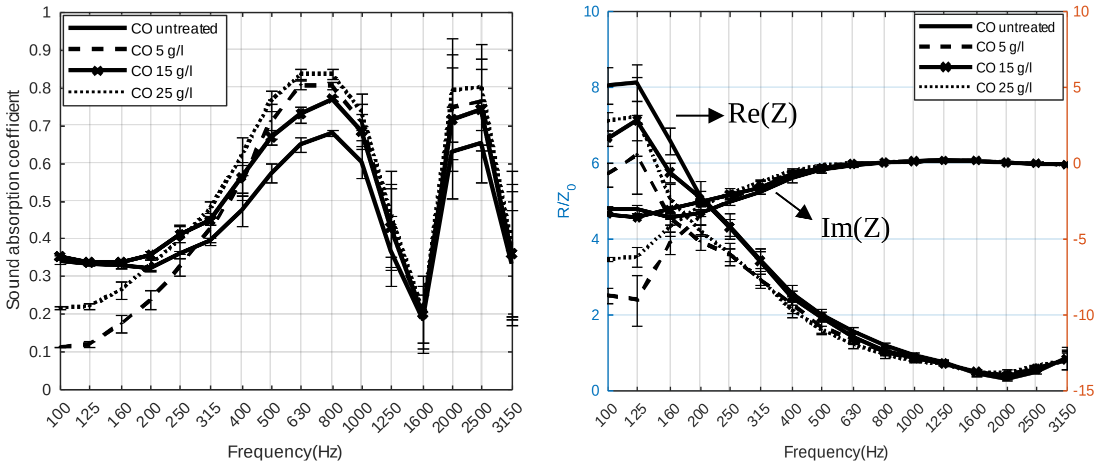
This study is aimed to explore the effect of doping on CO textile fabrics. First, a study of different microcapsules concentration with the same yarn density was performed and the results of sound absorption and impedance are presented in Figure 5. Then, a comparative analysis with the same doping percentage and different yarn density was accomplished (see Figure 6).

Table 1 summarizes the physical differences in yarn density and thickness of the two CO fabrics studied. Also, the airflow resistivity values of each CO sample untreated or doped with microcapsules are presented with their standard deviation, according to the procedure described in [32].

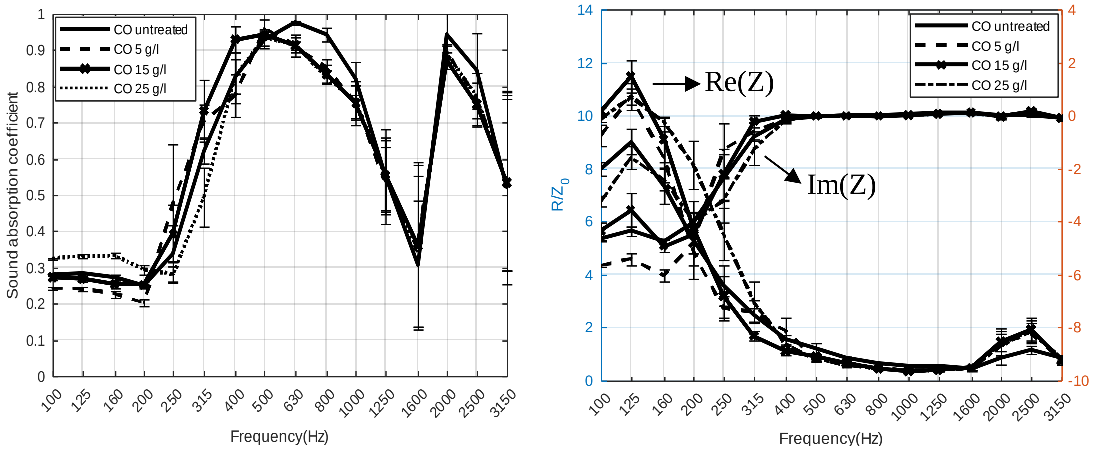
Table 1. Physical parameters of the cotton samples.

Fabrics	Thickness (mm)	Yarn density (g/m^2)	Airflow resistivity (kPa·s/m^2)
CO untreated	0.32	115	1272−1305
CO 5 g/l	0.29		1441−1448
CO 15 g/l	0.34		1192−1215
CO 25 g/l	0.32		1255−1298
CO untreated	0.64	210	634−640
CO 5 g/l	0.66		620−627
CO 15 g/l	0.66		621−622
CO 25 g/l	0.69		583−595

3.1 Cotton fabrics with the same yarn density and different MICs concentration:



(a) α (115 g/m^2) **(b)** Z (115 g/m^2)

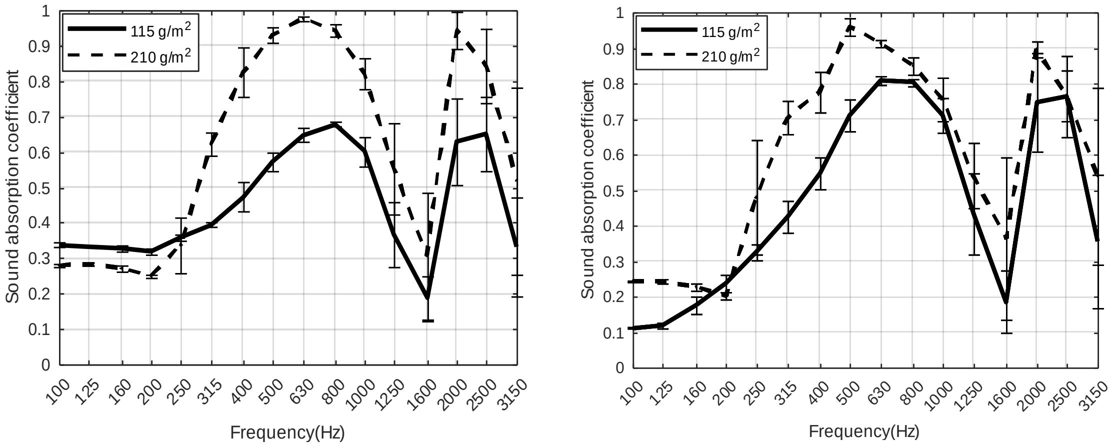


(c) α (210 g/m^2) **(d)** Z (210 g/m^2)

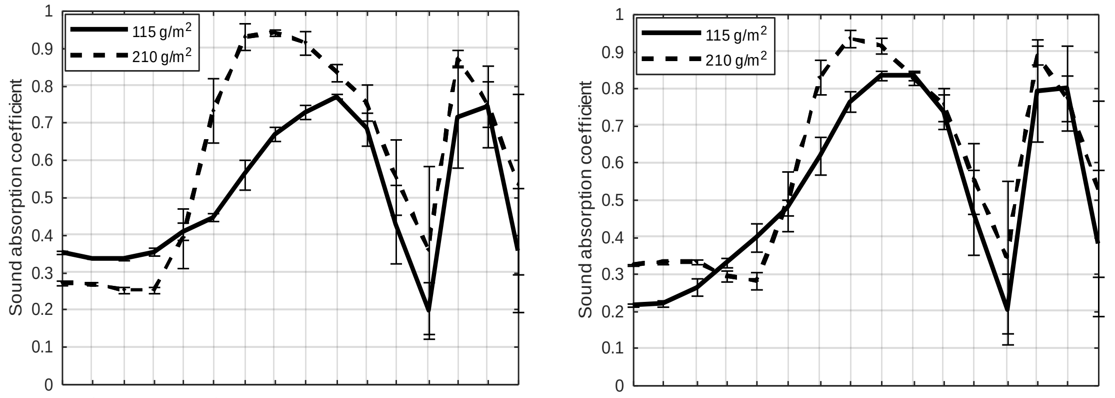
Figure 5. *Results of the normal incidence sound absorption coefficient and the specific acoustic impedance of the CO fabrics with different saturations of doping are presented. Also, measurements considering the thickness of an air cavity of 10 cm behind the CO sample studied. The dispersion percentage is measured in order to study the variability of the data and it is expressed as error bars.*

In Figure 5(a) and Figure 5(c), the normal incidence sound absorption coefficient of the CO fabrics studied with an air cavity is shown. In Figure 5(a), the results are shown for a yarn density of 115 g/m^2. The untreated CO fabric shows an increase in the sound absorption below the inferior frequency cutoff (f_i) of the impedance tube of 250Hz compared to CO fabrics doped with different MICs content. In the mid frequencies up to the upper frequency cutoff (f_u) of the impedance tube of 1600Hz, all doped CO fabrics have a α value higher than the CO untreated. At mid frequencies, CO fabric doped with 25 g/l presents the highest sound absorption coefficient (around 0.84) and no shift of the resonance peak is observed. At high frequencies, the error associated to the measurement (shown in bars in the figures) is quite high and no clear conclusions can be derived. In Figure 5(c) the results are shown for a yarn density of 210 g/m^2. MICs concentration has an influence on the position of the peak of sound absorption coefficient. It can be seen that there is a shift towards low frequencies. At mid frequencies, CO untreated has an α higher than 0.9. The sound absorption coefficient in CO fabrics doped is slightly lower. There is an improvement of sound absorption when the MICs concentration varies in Figure 5(a). In Figure 5(b) and Figure 5(d) the characteristic impedance of CO samples as a function of frequency is shown for both fabrics.

3.2 Cotton fabrics with different yarn densities and the same doping percentage:



(a) Untreated *(b) 5 g/l*



(c) 15 g/l *(d) 25 g/l*

Figure 6. *Normal incidence sound absorption coefficient of the CO textile fabric with different yarn density. Also, measurements considering the thickness of an air cavity of 10 cm behind the CO sample studied. Error bars expressed the deviation percentage of the measures.*

In all cases (untreated CO and doped CO with different MICs concentration: 5 g/l, 15 g/l and 25 g/l) shown in Figure 6, the higher the fabric weight the less is the sound absorption coefficient achieved at mid frequencies. The greatest difference is observed for the untreated case (a), where an improvement around 0.4 in α is achieved. Also, it can be clearly seen how the resonance frequency shifts towards lower frequencies when the density is increased, independently of MICs concentration. In the cases (a) and (c) below f_i, CO fabric with lower density possess high sound absorption. The sound absorption curve of CO fabric with a density of 115 g/m^2 reveals an increase trend at mid frequencies, in related with the increase of the volume fraction of microcapsules.

4. CONCLUSIONS

In this work, the sound absorption properties of CO samples with different fabric weight and different microcapsules concentration have been evaluated in a frequency range from 100 Hz to 3150 Hz with an air cavity of 10 cm. It can be seen that these CO fabrics present high sound absorption at mid frequencies.

The CO fabric results have been analysed under the hypothesis of homogeneity and assuming the same MICs size distribution in all doped samples.

The results show that the sound absorption is influenced by doping CO fabrics with MICs. Also, it is shown that the higher the fabric weight, the higher the sound absorption coefficient. Both MICs concentration and fabric weight have an influence on the position of the maximum sound absorption.

Although more tests are needed to clearly assess the effect of microcapsules on sound absorption, the results obtained show that MICs are can be useful to control the absorption properties of textile fabrics.

5. ACKNOWLEDGEMENTS

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