Sound absorption of doped cotton textile fabrics with microcapsules[1]

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Resumen

El desarrollo de nuevos tejidos textiles con microcápsulas depositadas en sus fibras está en auge dentro de la industria textil. El objetivo de este estudio se centra en analizar la influencia del dopaje de diferentes tejidos textiles de algodón con microcápsulas en el coeficiente de absorción sonora. Para determinar las propiedades acústicas de los nuevos materiales de absorción sonora, se utilizaron técnicas clásicas para la caracterización de materiales: el coeficiente de absorción sonora en incidencia normal y la resistencia al flujo de aire basada en el trabajo de Ingard&Dear. Se presenta un análisis comparativo entre la absorción sonora de tejidos de algodón con la misma densidad de hilo y diferente concentración de microcápsulas y diferentes densidades de hilo con el mismo porcentaje de dopaje. Los resultados muestran que la concentración de microcápsulas en correlación con la densidad de hilo tiene una influencia significativa en el coeficiente de absorción sonora.

Abstract

The development of new textile fabrics with microcapsules deposited on their fibers is on the rise within the textile industry. The aim of this study is focused on analyzing the influence of doping different cotton textile fabrics with microcapsules on the sound absorption coefficient. In order to determine the acoustic properties of the new sound absorbing materials, classical techniques for materials characterization were used: the sound absorption coefficient at normal incidence and the airflow resistance based on the Ingard&Dear work. A comparative analysis between the acoustic absorption of cotton fabrics with the same yarn density and different concentration of microcapsules and different yarn densities with the same doping percentage is presented. Results show that the concentration of microcapsules in correlation with the yarn density has a significant influence in the sound absorption coefficient.

Keywords: sound absorption; cotton textile fabrics; microcapsules.

1. Introduction

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

In the last few 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 because of the excess of sound produced mainly by human activities [3]. A few examples of this are tachycardia, pupil dilation, fatigue, hearing loss, stress, headache, less blood supply, decreased working capacity, and cardiovascular disorders.

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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]. All these materials have in common characteristics of materials that absorb sound. At present, this trend is changing and proof of this are the European Research and Innovation programs (H2020 and H2030) [5-6]. Nowadays, research should pay attention to develop new absorbent materials in order to replace other materials more aggressive towards the environment [7]. The idea is to use natural fibers from recycled materials instead of petroleum derivatives, which can become acoustic materials applicable to environment, construction, transport, industry and other areas [8-11].

In the textile industry, many wastes are generated during manufacturing processes. 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 [12, 13]. 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 [14,15], such as museums, theaters, opera houses and other spaces with the objective of providing the most sound quality by using carpets or curtains as an example. 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 [16].

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 [17]. In 1990, Shoshani showed in [18] that some intrinsic parameters analyzed of nonwoven fiberwebs and woven fabrics, like number of fiberwebs layers, fiber contents and the opening angle between individual panels, have a small effect on the sound absorption coefficient at low frequencies, but a significant effect at high frequencies. In 2007, Na et al. investigated in [19] the sound absorption properties of micro-fiber fabrics. With the same thickness, micro-fiber fabrics have higher sound absorption than traditional textile fabrics due to its greater surface area, resulting in higher airflow resistance. In 2012, Chevillotte studied in [20] a porous multilayer controlled by a woven fabric in order to enhance the sound absorption performance. The results evidenced an improvement of sound absorption at low frequencies, and recently, Segura-Alcaraz et al. researched in [21] the best combination fabric-nonwoven and the results presented showed a good interaction between both of them obtaining thermal effects of the nonwoven and resonant effects of the fabric causing a significant variation in the sound absorption coefficient.

Due to the rapid evolution in textile engineering, Nelson G. (1991) considered the use of microcapsules (MICs) in textile fabrics for the first time [22]. With MICs is possible to confer new properties to textile fibers in order to improve acoustic properties with respect to traditional nonwoven textiles [23, 24].

MICs are micrometric particles composed of one or more active ingredients that consist of a membrane (outer layer) that encompasses the active compound in the nucleus [25]. 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 [26]. 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 [27, 28].

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 contribution, we evaluate the influence of doping cotton fabrics with MICs by measuring the sound absorption coefficients with an impedance tube and using an air-cavity between fabric sample and the rigid end. A comparative analysis of cotton (CO) fabrics with the same yarn density and with different content of microcapsules is presented. The effect of the different yarn densities with the same doping percentage are also studied. Through the doping of the textile fabrics with MICs, it is possible to control the sound absorption.

2. Materials and methods

2.1. Materials

Cotton has been widely used in the textile industry for its biodegradable natural fibre, permeability, softness, comfort and high wettability [29]. In this study, CO fabric samples were obtained with a chemically and optically bleached. Two cotton fabrics from the same family but with different grammage, dyeing and yarn density have been analyzed in this manuscript. It was a twill weaved fabric with 115 g/m^2 and 210 g/m^2 and no chenille was included (see Fig. 1).

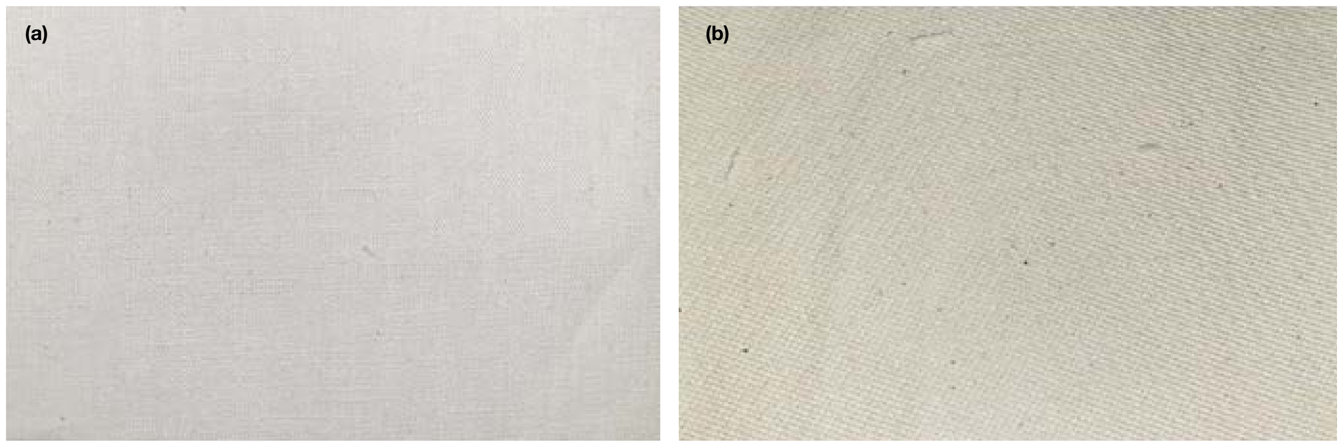


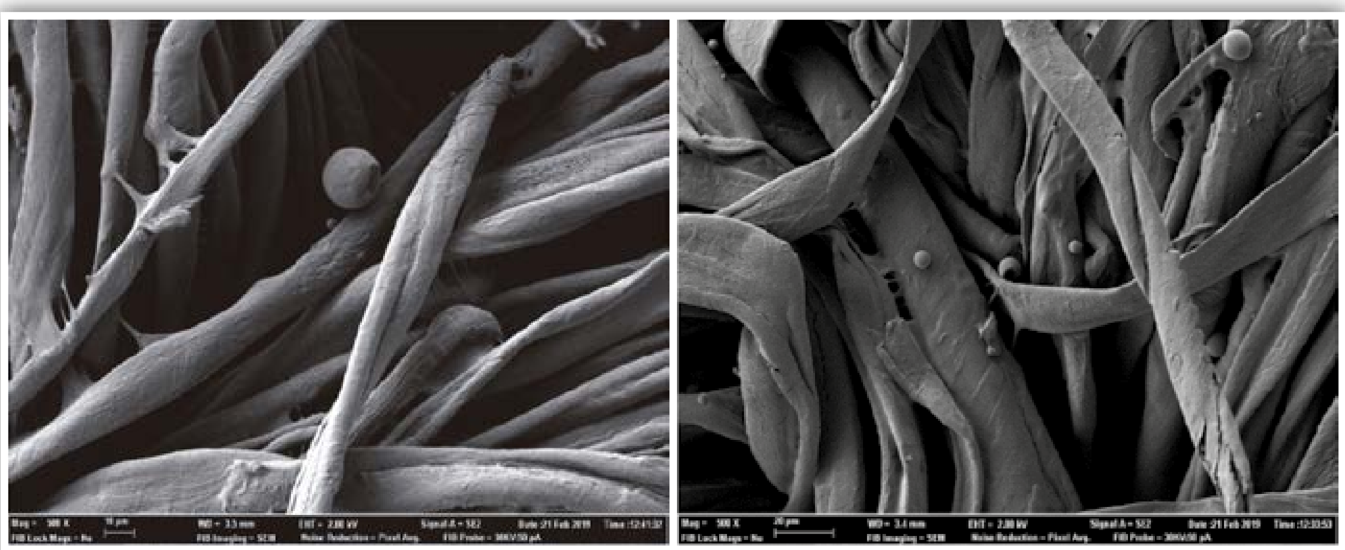
Figure 1. Cotton textile fabrics used in this study. Left: CO fabric with a yarn density of 115 g/m^2; Right: CO fabric with a yarn density of 210 g/m^2.

2.2. Adhering microcapsules on fabrics

Microcapsules were deposited on the surface of the fabric by padding. It is an impregnation technique, which consists of a rapid immersion process of the textile sample and two squeezing rolls press the liquid from both sides in the treatment bath, to force the substrate to pass through the fibres. The squeeze roll speed and pressure were regulated in order to obtain 80% wet pick-up [30]. The padding process was made with a horizontal foulard (2608 TEPA). The microcapsules applied on the woven fabrics are resistant to breakage and rubbing under normal conditions.

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 MIC concentrations: 5 g/L, 15 g/L, and 25 g/L. To complete the adhesion process between fibres and MICs, the CO samples were dried in a horizontal infrared dryer during 180 s at a temperature of 105º C.

MICs are imperceptible to the human eye due to its micrometric size. Field Emission Scanning Electron Microscope (FESEM) mod. ZEISS ULTRA 55 was used to observe the surface of the fabrics with high resolution (see Fig. 2). 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 [31, 32]. Each cotton sample was fixed on standard sample holder and the sputter-coated with a thin film of gold/platinum metal under vacuum conditions. This process was done in a Sputter Coater BAL-TEC mod. SCD005.



(a) MICs content: 5 g/L

(b) MICs content: 10 g/L

Figure 2. FESEM micrographs of cotton fabrics examined with suitable accelerating voltage of 2 kV and 500X magnifications. (a) Sample surface of CO fabric doped with MICs content of 5 g/L; (b) Sample surface of CO fabric doped with MICs content of 10 g/L.

2.3. Experimental setup

In the Higher Polytechnic School of Gandia at the Universitat Politècnica de València the measurement campaign was carried out. In order to characterize acoustically the cotton fabrics, two different methods were used: the standard ISO 105342:1998 [33], in order to determine the normal incidence sound absorption coefficient and the guidance proposed by Ingard&Dear in order to measure specific airflow resistance [34].

2.3.1. Sound absorption coefficient

According to the standard procedure detailed in [33], this method requires an impedance tube, two fixed microphone positions and a digital signal analysis system (Pulse LabShop v.22.2.0.197).

The impedance tube used is a rigid, methacrylate, smooth, transparent and airtight duct with circular cross section of 4 cm. At one end of the tube, a sound source (Beyma CP800Ti loudspeaker) is placed; at the other end, an air-cavity of 10 cm is mounted (see Fig. 3). The pressure signal in each position is recorded by using two free-field Brüel&Kjær pressure microphones (type 4190 1/2-inch). The usable frequency range is limited from 100 Hz to 3150 Hz based on the distance between microphones, the precision of the signal processing equipment and the tube inner diameter [33]. In order to ensure incident plane waves $\lambda >> 1.7D$. In Fig. 4a the experimental setup used in this test can been seen in considerable detail.

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

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

where r is the reflection coefficient, p_1 and p_2 are the acoustic pressures recorded by each microphone, k is

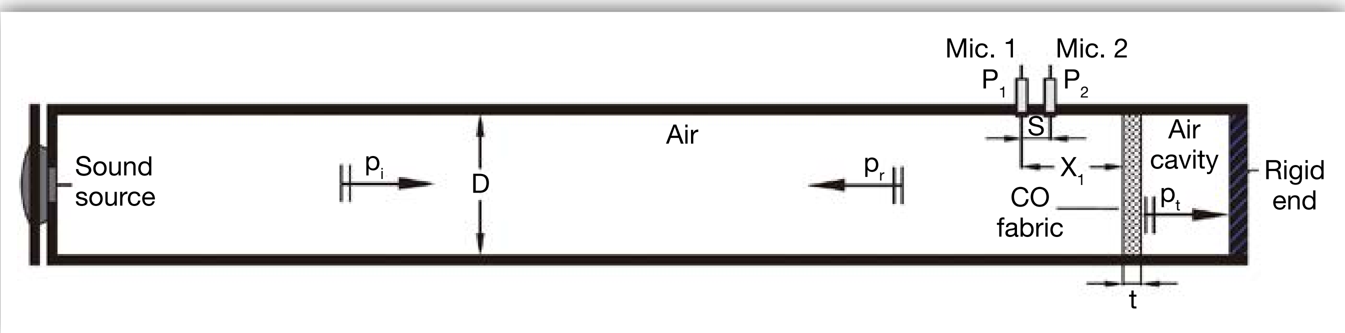
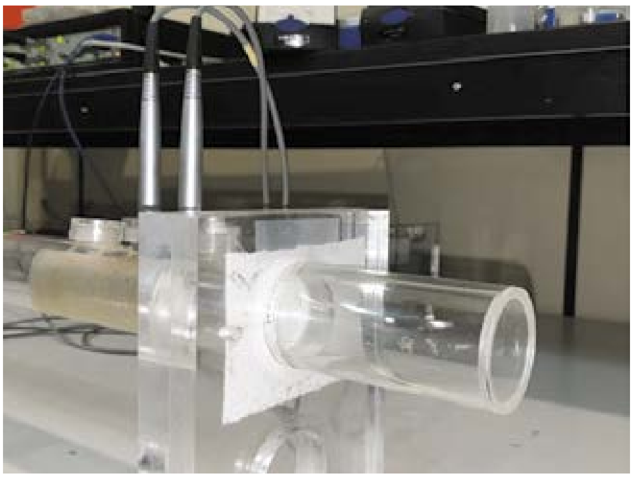
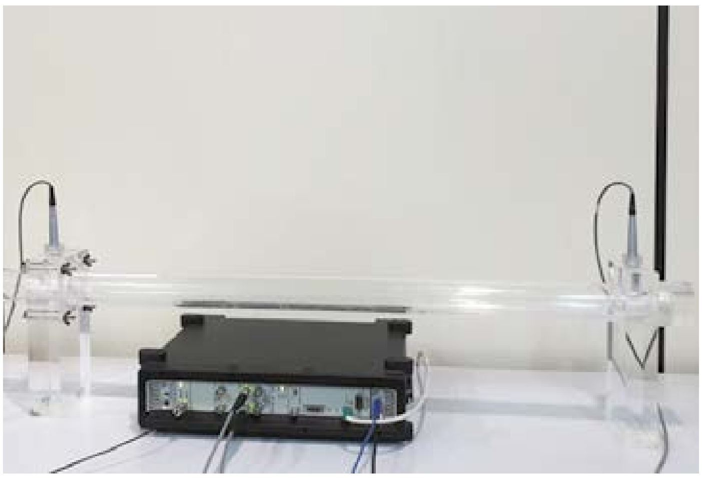


Figure 3. Schematic diagram of the impedance tube with an air-cavity of 10 cm used to measure the normal incidence sound absorption coefficient in accordance with the standard ISO 10534-2:1998. D is the tube inner diameter, p_i is the sound pressure of the incident wave, p_r is the sound pressure of the reflected wave, p_t is the sound pressure of the transmitted wave, and t is the sample thickness.



(a) Air-cavity method



(b) Ingard&Dear method

Figure 4. Experimental setup using the impedance tube. (a) Measurement of normal incidence sound absorption coefficient with an air-cavity; (b) Measurement of the airflow resistance according to Ingard&Dear method.

the wave number, x_1 and x_2 are the distances between both microphones to the CO sample.

The complex reflection coefficient, r, is obtained from the Eq. 1 and it can be observed as follows:

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

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 Eq. 2 as follows:

$$Z/\rho c_0 = R/\rho c_0 + jX/\rho c_0 = (1+r)/(1-r), \qquad (3)$$

where R is the real part, X is the imaginary part and ρc_0 is the characteristic impedance.

From Eq. 3 is calculated 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 by

$$\alpha_n = 1 - |r|^2. \qquad (4)$$

2.3.2. Airflow resistance

The airflow resistance evaluate the difficulty of an air stream to flow through the CO fabric per unit thickness (see Fig. 4b). The experimental setup is based on the indirect method proposed by Ingard&Dear obtaining the value of the specific airflow resistance under certain limitations [34].

In this method, the length of the impedance tube must be an odd multiple of a quarter wavelength of the sound in order to resonate. At low frequencies, and on the odd frequencies of $\lambda/4$, the airflow reactance is small compared to the airflow resistance, so the following simplification can be done:

$$\theta \approx \left|\frac{p_1}{p_2}\right| = \left|\frac{1}{H_{12}}\right|. \qquad (5)$$

It is possible to obtain the airflow resistance finding the minimum of the imaginary part of the pressure ratio p_1/p_2. For all cotton fabrics, the minima were observed at 100 Hz, 300 Hz, 500 Hz, 700 Hz and 900 Hz, approximately. Thus, it is possible to calculate the average values of the airflow resistivity, σ, (airflow resistance divided by the sample thickness) as follows:

$$\sigma \approx \left(\frac{\rho_0 c_0}{t}\right)\left|\mathrm{Im}\left(\frac{1}{H_{12}}\right)\right|, \quad \left[\frac{\mathrm{Pa}\cdot\mathrm{s}}{\mathrm{m}^2}\right]. \qquad (6)$$

3. Results and discussion

This study aimed to explore the effect of doping cotton textile fabrics on the sound absorption. A study of different concentration of microcapsules with the same yarn density was performed and the results of sound absorption and impedance are presented in Fig. 5. A comparative analysis with the same doping percentage and different yarn density was accomplished (see Fig. 6).

Table 1 shows the physical differences in yarn density and thickness of the two CO fabrics studied. Also, the airflow resistivity values of each cotton sample untreated or doped with microcapsules are presented with their standard deviation, according to the procedure described in [34].

Table 1. Physical parameters of the cotton samples untreated and doped with different MICs concentration.

Type of CO fabrics	Thickness (mm)	Yarn density (g/m²)	Airflow resistivity (kPa·s/m²)
Untreated	0.32	115	12721305
5 g/L	0.29		14411448
15 g/L	0.34		11921215
25 g/L	0.32		12551298
Untreated	0.64	210	634640
5 g/L	0.66		620627
15 g/L	0.66		621622
25 g/L	0.69		583595

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

In Fig. 5a and Fig. 5c, the normal incidence sound absorption coefficient of the CO fabrics studied with an air cavity is shown. In Fig. 5a, the untreated CO fabric shows an increase in the sound absorption below the inferior frequency cutoff (f_i = 250 Hz) of the impedance tube compared to doped CO fabrics with different MICs content. In the mid frequencies up to the upper frequency cutoff (f_u = 1600 Hz) of the impedance tube, all doped CO fabrics have an α value higher than the untreated CO. 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 Fig. 5c,

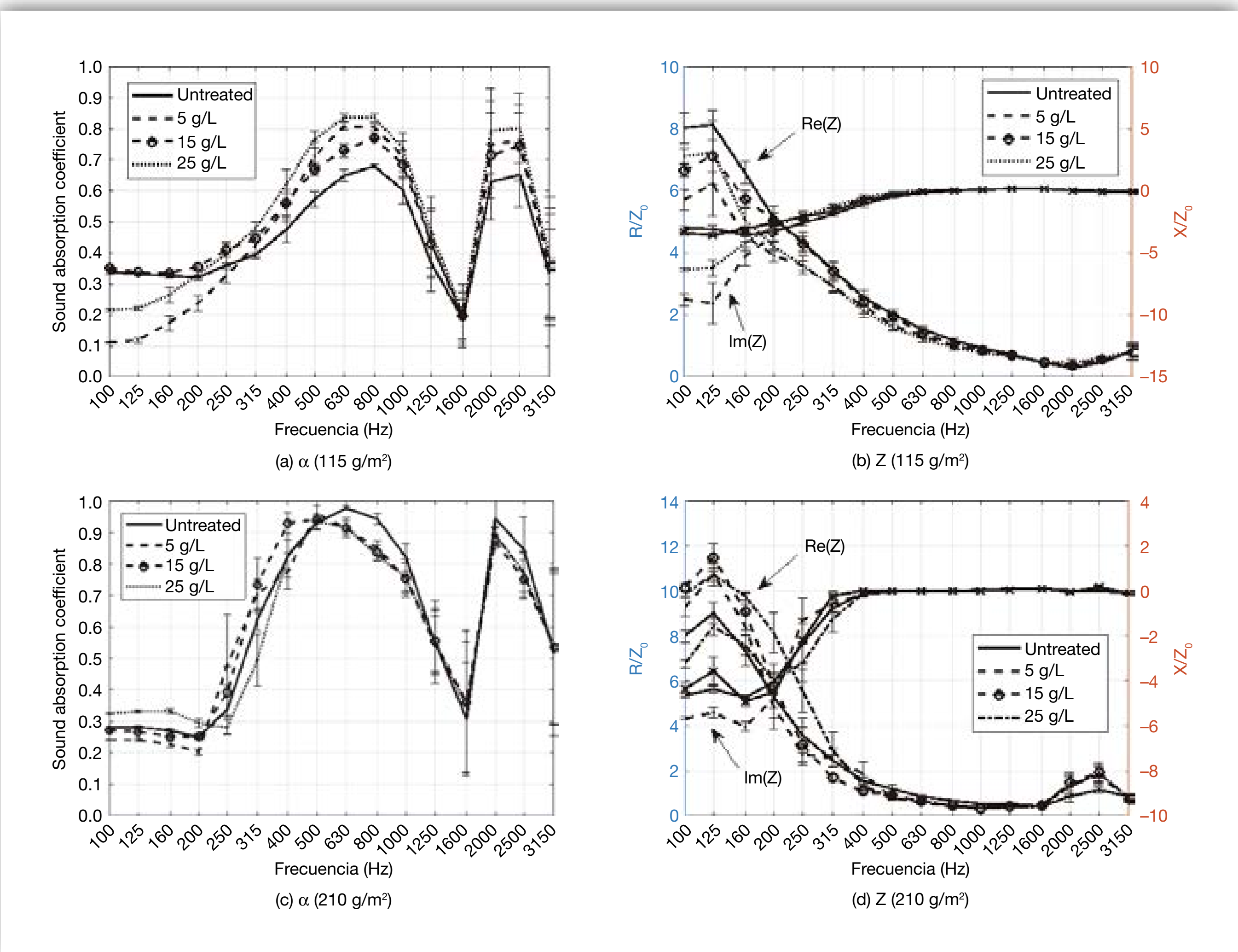


Figure 5. Results of the normal incidence sound absorption coefficient and the specific acoustic impedance of the CO fabrics with different saturations of doping are presented. Also, measurements considering the thickness of an air cavity of 10 cm behind the cotton sample studied. The dispersion percentage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

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, untreated CO has an α higher than 0.9. The sound absorption coefficient in doped CO fabrics is slightly lower. There is an improvement of the sound absorption when the MICs concentration varies in Fig. 5a. In Fig. 5b and Fig. 5d, the characteristic impedance of CO samples as a function of frequency is shown for both textile fabrics.

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

Fig. 6 shows in all cases studied (untreated and doped cotton with different MICs concentration: 5 g/L, 15 g/L and 25 g/L) that the lower the fabric yarn density, the lower is the sound absorption coefficient achieved at mid frequencies. The greatest difference is observed for the untreated case (Fig. 6a), where the cotton fabric with a yarn density of 210 g/m² has an improvement in α around 0.4. Also, it can be clearly seen how the resonance frequency shifts towards lower frequencies when the yarn density is increased, independently of MICs concentration. In the cases Fig. 6a and Fig. 6c below f_i, CO fabric with lower yarn density possess high sound absorption. The sound absorption curve of cotton fabric with a yarn density of 115 g/m² 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 yarn densities and different microcapsules concentration have been evaluated in an impedance tube with an air cavity of 10 cm. It can be

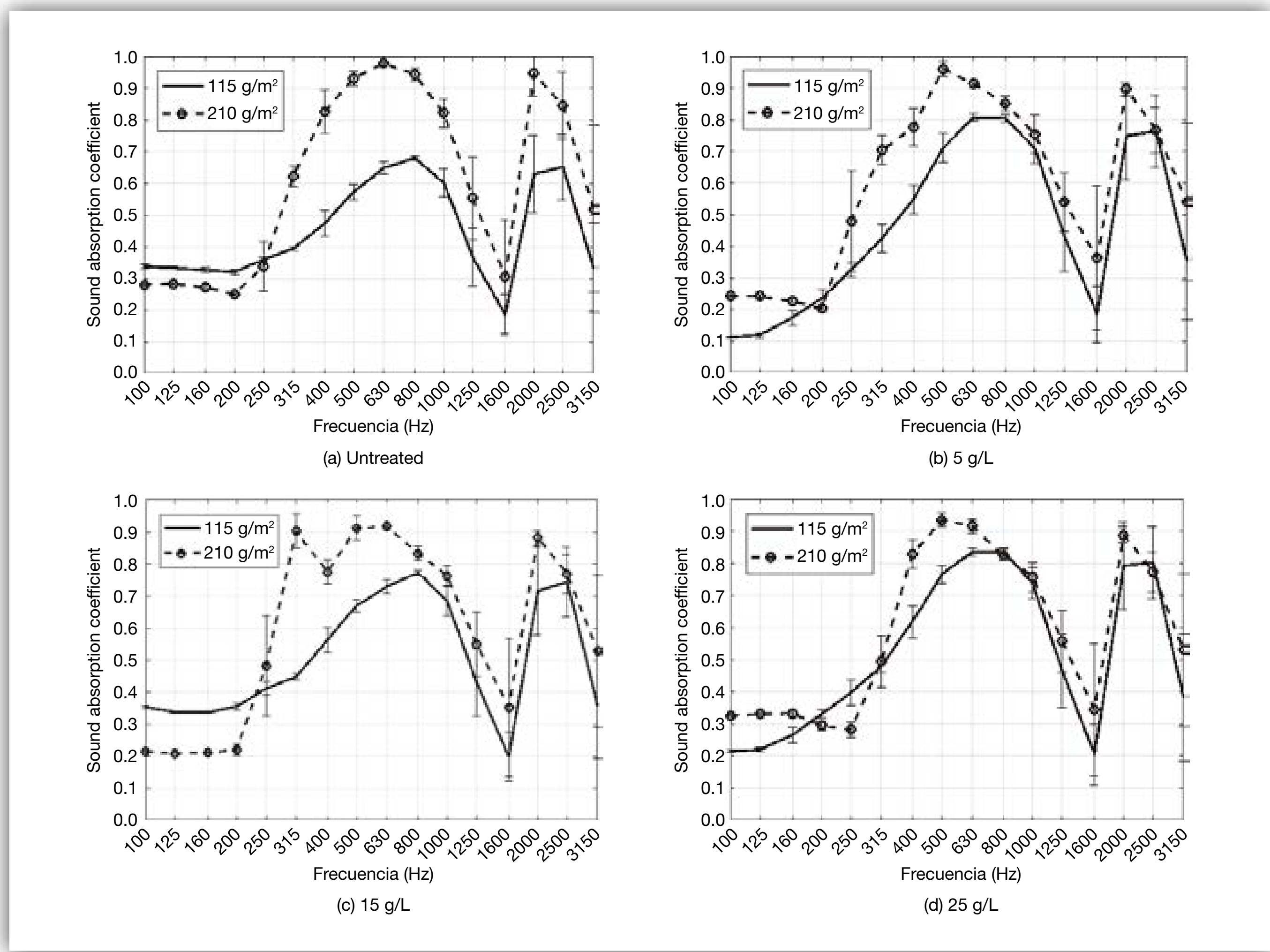


Figure 6. Normal incidence sound absorption coefficient of the cotton textile fabric with different yarn densities. Also, measurements considering the thickness of an air cavity of 10 cm behind the cotton sample studied. Error bars expressed the deviation percentage of the measures.

seen that these CO fabrics present high sound absorption at mid frequencies.

The CO fabric absorption 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 altered by doping CO fabrics with MICs. Both MICs concentration and fabric yarn density have an influence on the frequency of maximum sound absorption.

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

5. Acknowledgements

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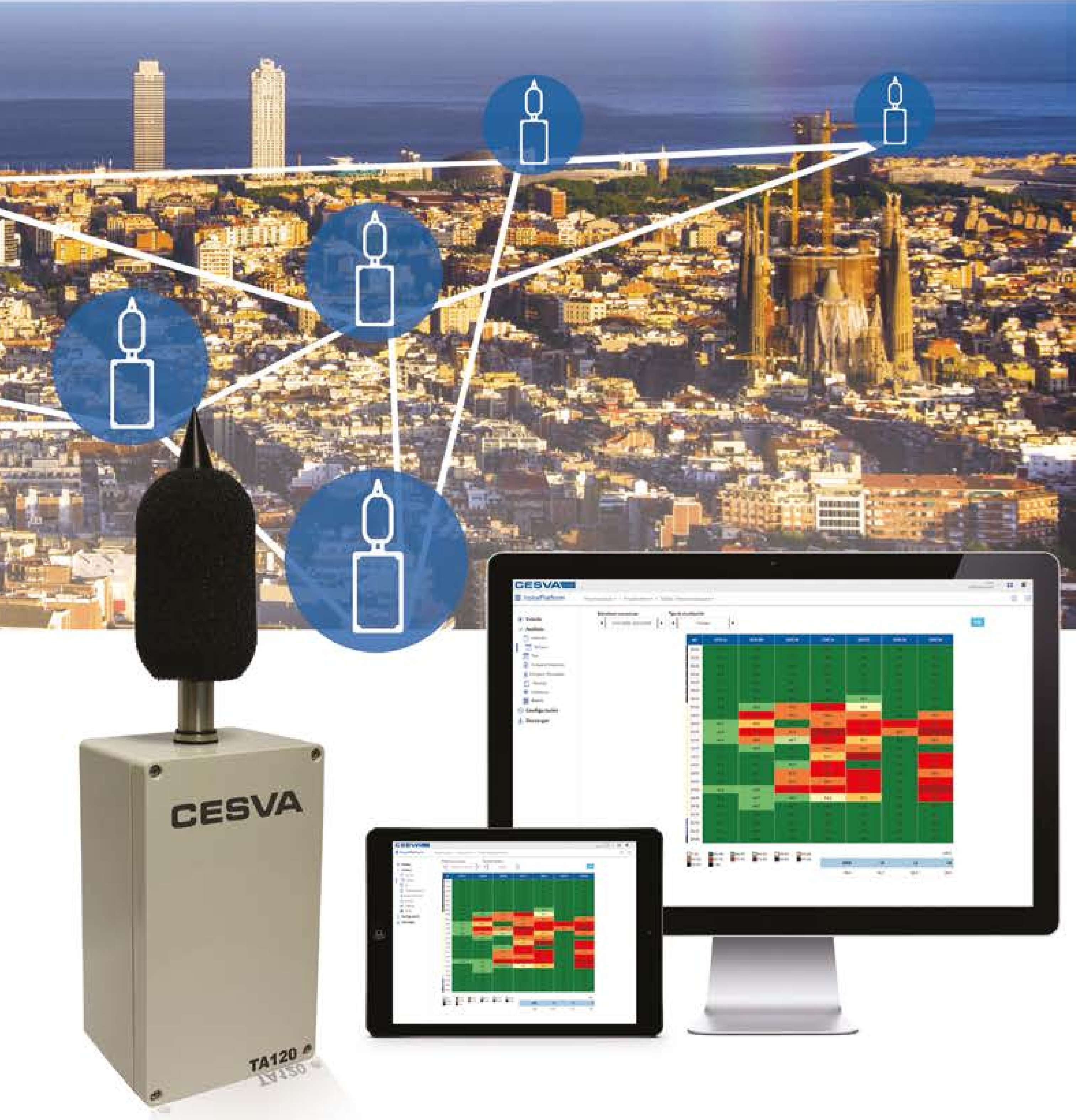

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