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EVALUATION OF THE ACOUSTIC PROPERTIES WITH INVERSE CHARACTERIZATION METHODOLOGY WITH THIN MATERIAL SAMPLE

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Abstract. As known, porous materials are good acoustical attenuators and widely used in acoustic filters. However, to determine the properties of these materials it is a complex process due to the non-homogeneous structure. For the evaluation of the acoustical properties, it is required high precision equipment, in other words, high cost. In this present work , an alternative method using a software with an optimization algorithm, estimate with good agreement, some of these acoustical properties, such as flow resistivity, porosity, tortuosity, viscous and thermal length. The inverse method denoted by Johnson-Champoux-Allard (JCA) is applied within optimization algorithm and compared with the experimental characterization (absorption coefficient and surface impedance of the material) using the impedance tube. The comparison in this work, between the JCA model and the experimental showed good convergence for the estimation of the five properties above of the common foam and coconut fiber.

Keywords: Porous material, inverse characterization, JCA model, genetic algorithm, natural fibers

1. INTRODUCTION

Sustainable materials are more often requested nowadays in acoustic applications, since the synthetic materials are generally toxic when burned and unviable for discard on the environment, researches are growing on this kind of materials, which got good potential for acoustic uses.

Currently, Brazil have a fleet with more than 44 million automotive vehicles circulating (ANFAVEA, 2018) and the most part of this vehicles are concentrated in the big cities, in that case, natural materials are being developed to minimize the noise pollution, and coconut fiber is one of them and it was chosen in this work. The husk of the coconut fiber are agricultural wastes and they have been used in many new industries applications, such as acoustic filters, vehicle roof trim, structural materials and thermal isolation.

Natural fibers are more complex to characterize due to its complexity. The fiber distribution are not the same for all samples, which makes the samples different even using the same amount of fibers and glue.

Firstly, the purpose of this paper is to evaluate the five properties denoted by Allard and Champoux (1991): flow resistivity (σ), porosity (ϕ), tortuosity (α_∞), viscous (Λ) and thermal length (Λ'). Using the impedance tube is possible to estimate the impedance surface (Z_s) and the absorption coefficient (α) of the common foam and the husk of coconut fiber. The results obtained are used on the genetic algorithm (GA) with the JCA methodology. Secondly, the GA estimates the five properties and compare with the experimental procedure.

2. METHOD DESCRIPTION

In this topic, theoretical model by Johnson-Champoux-Allard (JCA) and the experimental procedure with the impedance tube by Chung and Blaser will be described, as well as the steps for the evaluation of the properties of the acoustic material using the genetic algorithm.

2.1   Theorical Model

This work is based on the Allard and Champoux (1992) paper. An inverse methodology to evaluate the properties of the fibrous and porous materials are mentioned. According to the author, five properties can be evaluated: flow resistivity (σ), porosity (ϕ), tortuosity (α_∞), viscous (Λ) and thermal length (Λ'). However, these properties are known as non-acoustic, but material properties. In addition, each property require a specific equipment for measurement, consequently, making impracticable due to the cost.

This work purpose an alternative method applying JCA's model. Although, instead of using specific equipment, a numerical software and an optimization algorithm will be used.

The authors evaluated two essential properties of the acoustic material, the bulk modulus (K) and the complex density (ρ) denoted by equations (1) and (2), respectively. Both bulk and complex density are dependent of all five properties mentioned above.

$$K(\omega) = \gamma P_0 \left(\gamma - \frac{(\gamma - 1)}{\left(1 + \frac{\sigma \phi}{i \alpha_\infty \rho_0 N_{pr} \omega} \sqrt{1 + \frac{4i\alpha_\infty^2 \eta \rho_0 N_{pr} \omega}{\sigma^2 \Lambda^2 \phi^2}} \right)} \right)^{-1} \tag{1}$$

$$\rho(\omega) = \alpha_\infty \rho_0 \left[1 + \frac{\sigma \phi}{i \alpha_\infty \rho_0 \omega} \left(\sqrt{1 + \frac{4i\alpha_\infty^2 \eta \rho_0 \omega}{\sigma^2 \Lambda^2 \phi^2}} \right) \right] \tag{2}$$

Where γ is the specific heat ratio of air, P_0 is the air pressure, ρ_0 is the air density, N_{Pr} is the Prandtl number, ω the angular frequency, η is the air viscosity, and i is the imaginary part.

Afterwards, it is possible, according to the author, to estimate two important acoustic properties: the complex wave number (Γ) and the characteristic impedance number (Z_c), denoted by equations 3 and 4, respectively.

$$\Gamma(\omega) = i\omega [\rho(\omega) / K(\omega)]^{1/2} \tag{3}$$

$$Z_c(\omega) = [\rho(\omega) K(\omega)]^{1/2} \tag{4}$$

Finally, the surface impedance and absorption coefficient can be obtained, represented by equations (5) and (6), respectively.

$$Z_s(\omega) = Z_c(\omega) \coth(\Gamma(\omega) l) \tag{5}$$

$$\alpha = \left| \frac{Z_s - \rho_0 c_0}{Z_s + \rho_0 c_0} \right|^2 \tag{6}$$

Where l is the sample thickness and c_0 is the speed of the sound in the air.

2.2   Experimental procedure

In this topic, the main objective is the evaluation of the surface impedance and the absorption coefficient experimentally (mentioned in section 2.1).

An impedance tube (Figure 1) with samples of the coconut,10 mm thickness and foam samples, 40mm thickness, are tested (Figure 2). The method applied is according to Chung and Blaser (1980-I) and the ASTM E1050-10, where the authors uses two microphones to obtain the transfer function (*H*), denote by equation (7).

Figure 1 – Impedance tube –EuroAcoustic model SCS 9020 B/K , analyzer Brüel & Kjær Type 3160-A-042 and two microphones Brüel & Kjær Type 4935 de ¼''

Figure 2 – Extracted coconut sample and common foam sample

$$H_{12}(f) = \frac{p_2(f)}{p_1(f)}$$
(7)

Where p_2 is the sound pressure in microphone 2 and p_1 is the sound pressure in microphone 1.

The next step, with possession of the transfer function, is the measurement of reflection coefficient (*R*), consequently, the absorption coefficient, denoted by equation (8) and (10) respectively, even as the surface impedance, denoted by equation (9).

$$R(f) = \frac{H_{12} - e^{iks}}{e^{iks} - H_{12}} e^{2ikx_1} \tag{8}$$

Where k is the air wave number, s is the distance between microphone 1 and 2 and x_1 is the distance between the sample and the nearest microphone.

$$Z_s(f) = \rho_0 c_0 \frac{1 + R}{1 - R} \tag{9}$$

$$\alpha(f) = 1 - |R|^2 \tag{10}$$

The Figure 3 explain the steps mentioned previously, respectively. Firstly the sample manufacturing (coconut and common foam), the experimental methodology of the samples. Secondly, the experimental data applied on the Transfer Function Method (equation 7 and 8), posteriorly the experimental impedance surface and the absorption coefficient (equations 9 and 10).

Afterwards, the genetic algorithm (GA) optimize the experimental absorption coefficient and the impedance surface (measured on the impedance tube) to an empirical absorption coefficient and impedance surface curves, also given the five material properties mentioned in the Section 2.1.
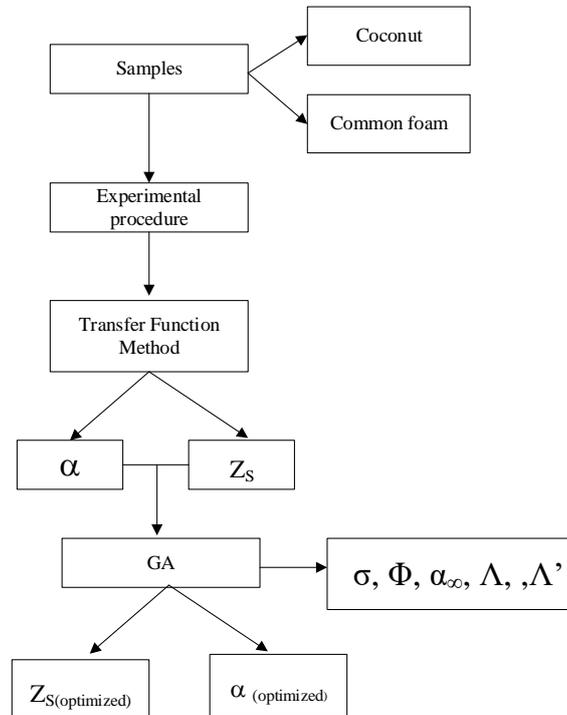

Figure 3 – Flow chart

3. RESULTS

In this topic, the comparison between the impedance surface and absorption coefficient, using GA and the experimental procedure with impedance tube are shown.

The results obtained experimentally now are used in the GA. The algorithm will estimate the five properties mentioned in section 2.1, fitting the best result compared to the experimental curves.

In Figure 4, are the normalized impedance surface and the absorption coefficient results: the impedance tube and the optimization with GA. In Figure 5, the same for the coconut fiber.

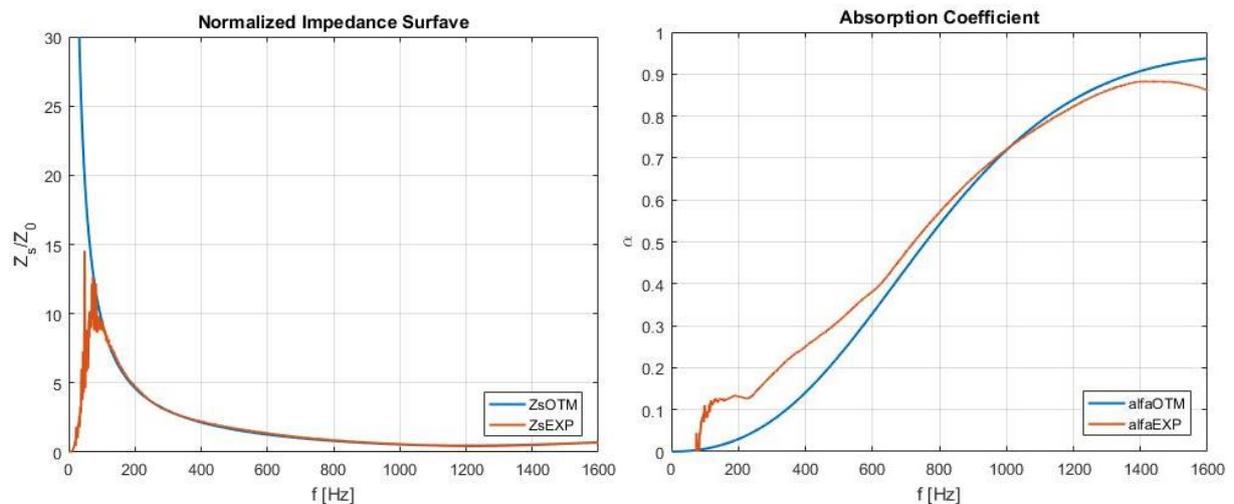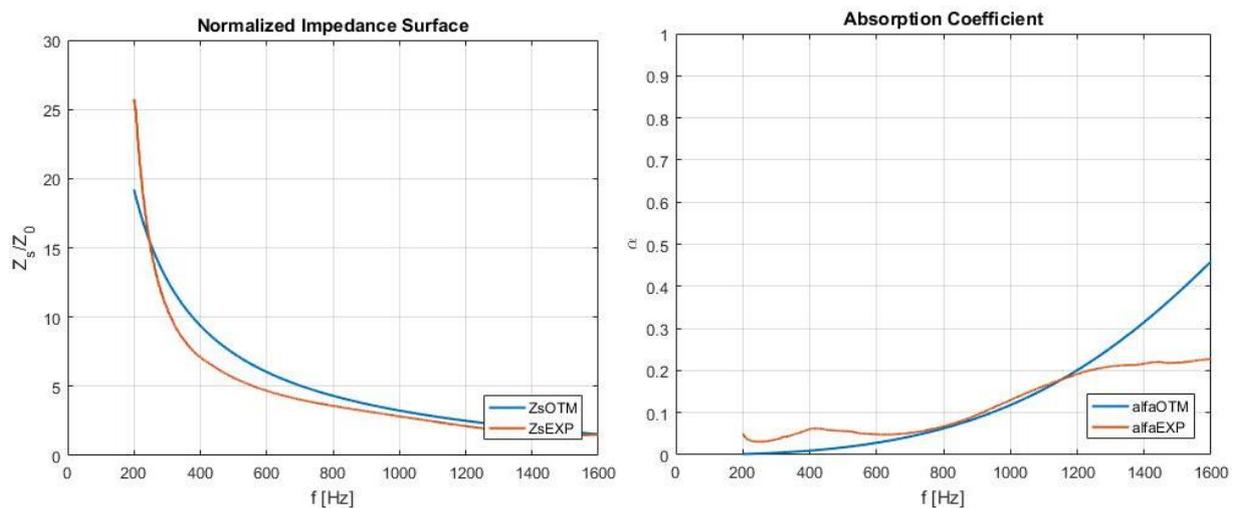Figure 4 – Absorption Coefficient and the normalized impedance surface of the common foam

Figure 5 – Absorption Coefficient and the normalized impedance surface of the coconut

4. CONCLUSIONS

The results obtained clearly shows that common foam have a better behavior compared to the coconut fiber. Firstly, thin (10mm thickness) materials are more difficult to characterize (Legat Filho, 2017 and Terashima, 2016). Secondly, the fiber distribution are not homogeneous when the samples are hand manufactured and the fibers have different diameters and length over the fiber (Lima, 2016). Although, both samples showed good convergence in specific range of frequency, since these properties are not frequency dependent but material properties.

For instance, the foam, between 600 to 1100 Hz and 700 to 1200 Hz to the coconut sample, on the absorption coefficient. For the normalized impedance, for the foam samples, almost the entire range have good convergence and for the coconut fiber, starting in 900 to 1600 Hz.

The following properties of the foam and coconut fiber estimated by the GA are respectively shown in Table 1.

	σ [rayl/m]	Φ	α∞	Λ [µm]	Λ' [µm]
Foam	4500	0.915	0.98	65	72
Coconut	3950	0.683	4.93	212	415

Table 1 – Table with optimized results for foam and coconut fiber

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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