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Sound propagation in activated carbon felts

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ABSTRACT

Granular activated carbon materials have been studied for some years and are now well-known for their ability to absorb sound at low-frequencies. This is attributed to the presence of sorption processes (adsorption and desorption) in nanopores. Activated carbon fibres also contain a considerable amount of nanopores but are light-weight and easier to use as they do not need containers. The aim of the study is to investigate the ability of activated carbon fibres to effectively absorb low frequency sound. The acoustical properties of activated carbon fibres are measured in an impedance tube to assess the importance of parameters such as specific surface area, fibre diameter, porosity and pore size at different scales. A model to predict the acoustic behaviour of the activated carbon fibres is also developed. This model takes into account different scales of porosity and the presence of sorption.

Key words: sound absorption, multi-scale material, porous material, sorption

I-INCE Classification of Subjects Number(s): 35.2

INTRODUCTION

For some years, the acoustic properties of Granular Activated Carbons (GACs) have been studied, motivated by their extraordinary abilities to absorb low frequency sound. Their internal structure and acoustical behaviour are described in Bechwati (1), Mellow et al. (2), Umnova (3) and Venegas (4). However, application of GAC can present practical challenges because it is a loose and relatively heavy material. This means that binders or encapsulation are required if GAC is to be used in real-world applications.

Activated Carbon Felts (ACFs) in contrast, do not require binders, are lightweight, and can bend easily. Their uses include worker protections from hazardous gases such as Toluene and water and air filtration. The fabrication of ACFs included carbonization and activation in a one-step process (5). Carbonization is applied to the fibres to remove the non-carbon substances. Activation is a process that aims at widening and/or creating porosity and is based on solid-gas interaction at high temperatures e.g. 650 to 950°C.

The acoustical properties of AC felts have been investigated in Shen and Yiang (6,7). Therein the effects of bulk density, fibre diameter, thickness, carbonization temperature and carbonization rate, activation temperature and activation time on sound absorption have been presented. However, no model has been proposed for predicting the acoustical properties of ACFs. In this work, the measurements of sound absorption by commercial ACFs for different thicknesses and bulk densities are described and compared with a model that takes into account the microstructure of the material and the presence of sorption in nanopores.

1. Description of the Activated Carbon Felts

The tested ACFs have fibre diameter of approximately 20 μm and the bulk densities are in between 60 and 120 kg/m^3. Considering that the fibres are composed of carbon, the overall porosity can be

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deduced from this as ranging from 94.55% to 97.27%. The fibres contain pores of different sizes. In this work inter-fibre pores of two sizes are considered; according to IUPAC classification they correspond to mesopores (2-50nm) and micropores (<2nm) respectively.

In most documentations, ACFs are ranked by specific surface area (m^2/g) using the Brunauer, Emmett and Teller (BET) model. An increase of the degree of activation implies a greater specific surface area, pore volume and pore diameter (8).

Assuming a high permeability contrast between the mesoscale and microscale/nanoscale, the mesoporosity (i.e. the volume fraction of voids between the fibres) of the ACF can be deduced from flow resistivity measurements (9). Flow resistivity of ACF has been measured using a standard rig following the procedure described in BS EN 29053:1993. Results for different thicknesses are given in Table 1.

Table 1 – Flow resistivity measurements of Eurocarb ACF 1200

d (cm)	σ_0 (Pa.s/m²)
1	85816.63
2	87153.80

The static flow resistivity value is obtained by linear regression of flow resistivity for various flow rates (Figure 1). As expected, the static flow resistivity of the Eurocarb ACF is stable as thickness is increased.

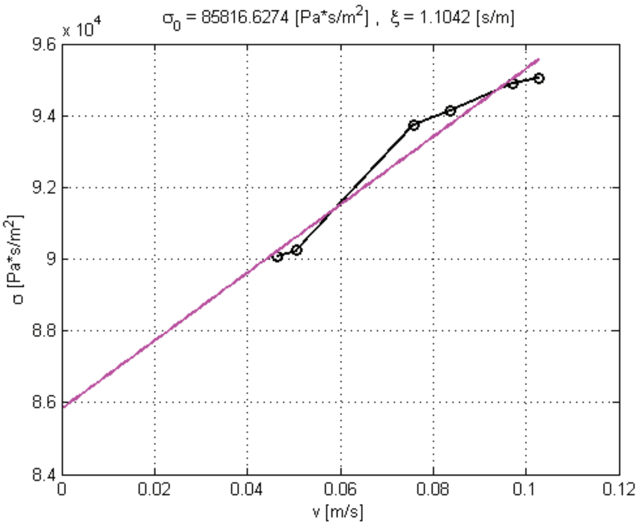

Figure 1: Flow resistivity measurements for a 1cm layer of Eurocarb ACF 1200

The mesoporosity has been deduced using the following equation (3):

$$\sigma_0(K=0) = \frac{8(1-\phi_p)\eta}{(-2\ln(1-\phi_p) - 2\phi_p - \phi_p{}^2)a^2} \tag{1}$$

where a is fibre radius, η is the dynamic viscosity ϕ_p is the mesoporosity. This relation assumes that fibres are equidistant, parallel and arranged perpendicular to sound propagation direction. The deduced value of ϕ_p is 0.9.

2. Modelling of the Activated Carbon Felts

The mathematical model for ACFs is based on the work done for granular activated carbon by Venegas (4) and Venegas and Umnova (9, 10). The ACF is modelled as a material with three scales of porosity; mesoscopic, microscopic and nanoscopic scales. In this work, the model proposed in (4) has been modified to account for the different mesoscopic geometry of fibrous materials compared with that of granular ones.

The fibres are considered to be identical and perpendicular, of radius a, and perperndicular to the acoustic wave propagation direction. Dynamic viscous and thermal permeabilities associated with the mesosocopic scale are calculated using equations 4.65 and 4.73 in reference (4). The pressure diffusion function is modified according to the geometry under study and is given by equations 5.107, also of reference (4).

The model requires the knowledge of the following parameters: fibre radius (measured), mesoporosity (deduced from flow resistivity measurements), micro and nanoporosities (their combination is deduced from the overall porosity and mesoporosity), nanopore and micropore radii (fitted) and the ratio of adsorption constants, i.e. the Langmuir constant.

The latter is derived from the measured value of the low frequency limit of bulk modulus using the following equation, taken from (10):

$$E(\omega \to 0) = E_0 = \frac{P_0}{\phi} \frac{1}{(1 + \rho_N \rho_0^{-1} \psi)} \quad (2)$$

where $\psi = P_0 b/(P_0 b + 1)^2$. P_0 is the equilibrium pressure, $\rho_N = 2m/r_n S_m$ the maximum density increment due to sorption with S_m the area occupied by each molecule, m mass of the saturating fluid molecule, ρ_0 is the equilibrium density, ϕ is the material porosity b is the Langmuir constant $b = k_a/k_d$, k_a is the adsorption coefficient (in $Pa^{-1}s^{-1}$) and k_d is the desorption coefficient (in s^{-1}).

The static bulk modulus is obtained by measuring the bulk modulus using the two-thickness method and extrapolating the real part of this effective parameter to zero, as proposed in (4). The results are presented in Figure 2.

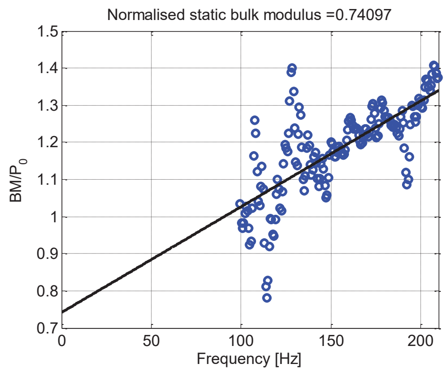

Figure 2: Bulk modulus at low frequency from two measurements of 4 and 8cm of Eurocarb ACF 1200

The static bulk modulus plotted on Figure 2 has some discrepancies due to the practical difficulties of conducting impedance tube measurements at low frequencies and low absorptions. However, the results seem to show a similar trend to that found in granular activated carbons, i.e. the normalised bulk modulus tends to a value smaller than unity.

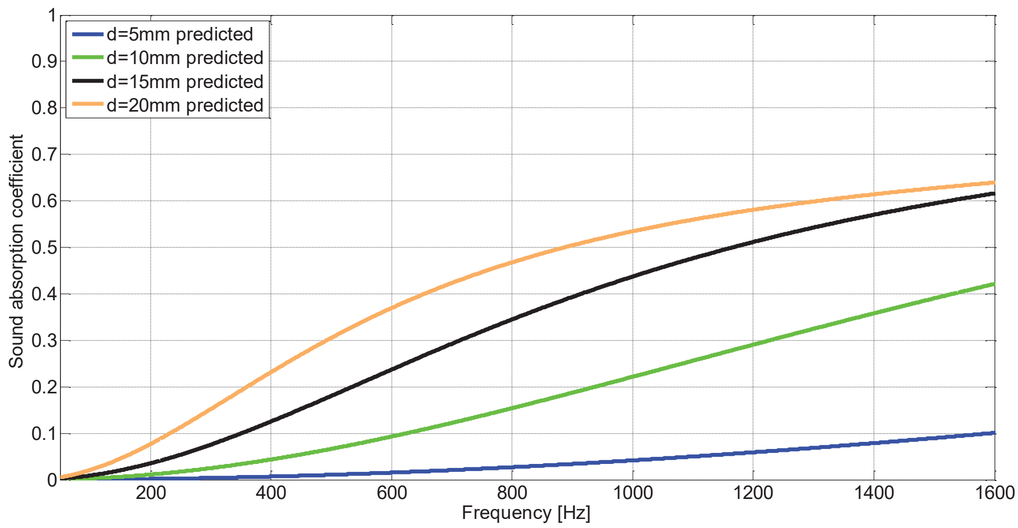

Figure 3: Normal incidence sound absorption coefficients of Eurocarb ACF1200 obtained by predictions

The absorption coefficient values predicted by the model are shown in Figure 3 along with those measured ones. The parameters used for modelling are displayed in Table 2. A good qualitative agreement is found between the predicted and measured values.

Table 2: Parameters of the model for the Eurocarb ACF1200

a	ϕ_p	ϕ_m	r_m	ϕ_n	r_n	b	ϕ_{th}
9.78µm	0.9	0.5277	4µm	0.05	4.953nm	6.271e-05	0.9551

Here ϕ_m is the microporosity, r_m is the micropore radius, ϕ_n is the nanoporosity, r_n is the nanopore radius and ϕ_{th} is the overall porosity. The nanoporosity value is very low so the material appears to behave like a double porosity material rather than triple porosity one.

3. Measurements of the Activated Carbon Felts

An impedance tube is used to measure the normal incidence sound absorption coefficients with the two-microphone method as described in the standard ISO 10534-236 (12). Samples of Activated Carbon Felts from Eurocarb are tested for different thicknesses. The layer of the commercial ACF is 5mm. To measure thicker samples, different layers are stacked. The sound absorption coefficients are measured between 50 and 1400 Hz.

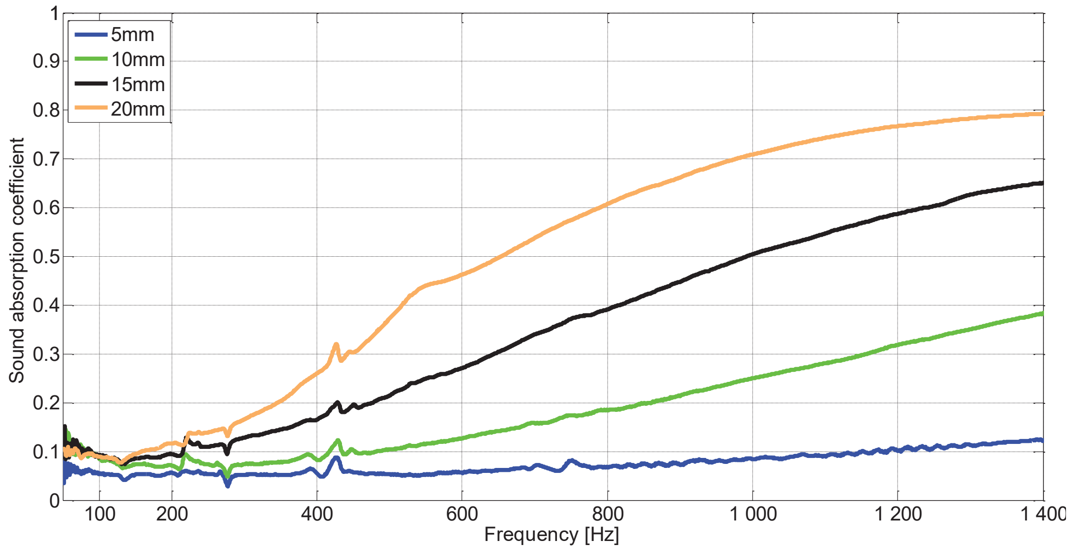

Figure 4: Sound absorption coefficients of the Eurocarb ACF1200

The sound absorption coefficients are plotted on Figure 4. An increase of the thickness of ACF leads to higher sound absorption coefficients, especially at low frequencies (e.g. 0.25 with a 20mm layer instead of 0.1 with a 20mm layer at 400 Hz).

In Figure 5, the predicted sound absorption coefficients are compared with the measured ones. A good agreement is obtained for 10 and 15 mm layers of ACF. The predicted sound absorption coefficient is underestimated compared with the measured ones. The sound absorption coefficient of the thickest layer e.g. 20mm provides the largest deviation. This results suggest that the model has to be improved to predict the behaviour of the ACF.

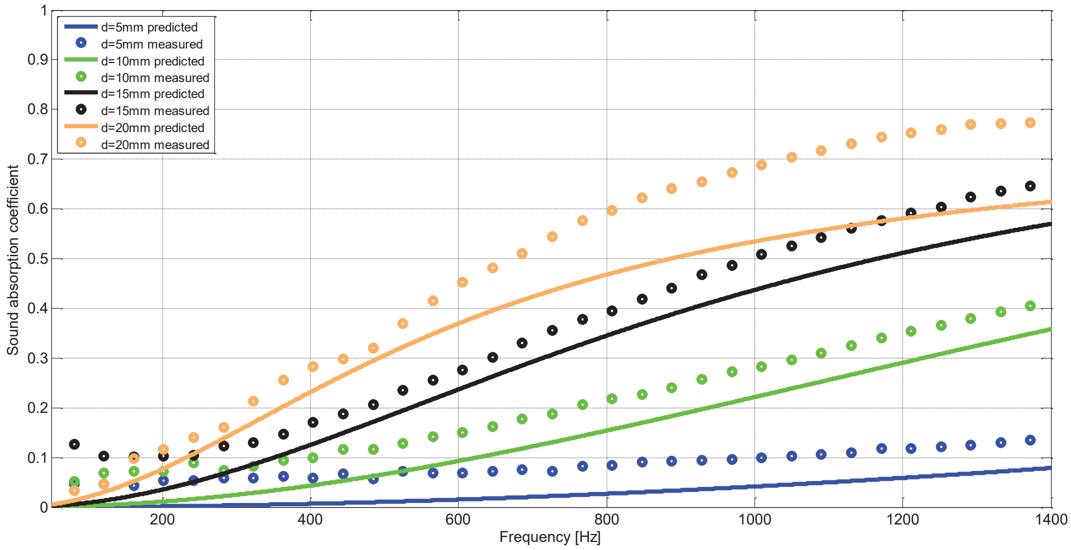

Figure 5: Comparison of the predicted vs. measured sound absorption coefficients for three different thicknesses of ACF 1200

The sound absorption coefficients of the Eurocarb ACF 1200 are now compared to another ACF with different density and made from Novoloid fibres (11) for which three different samples are shown in Figure 6. The sound absorption coefficients obtained for these ACF tend to have similar performances in comparison with the Eurocarb ACF 1200.

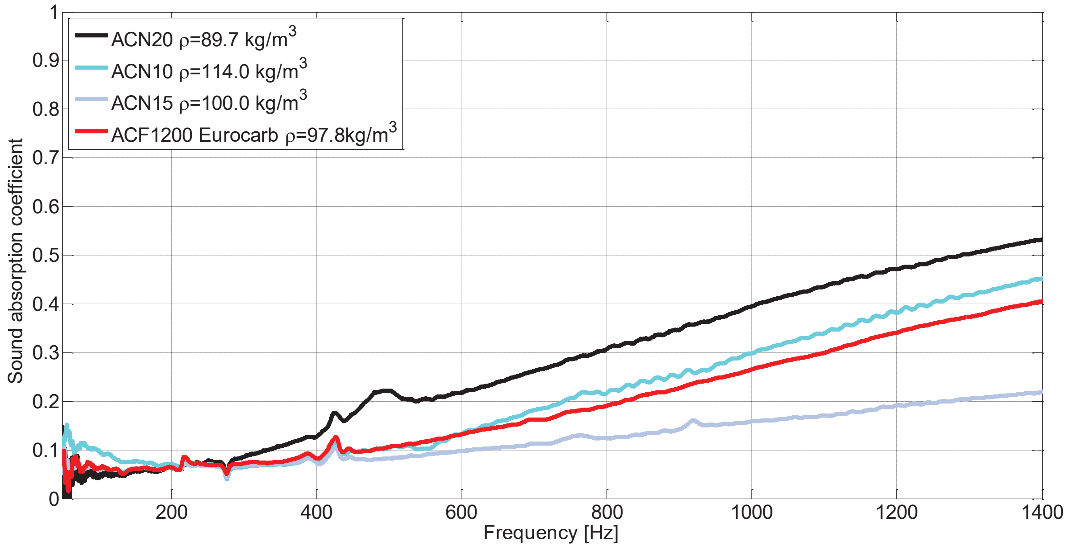

Figure 6: Comparison of the normal incidence sound absorption coefficients for different samples for a 1cm layer

The ACN 20 allows the best performances and has also the lowest density and appears to be a good canidate to be studied. Some of the ACFs, whose sound absorption are shown in Figure 6, are known to have a double-porosity structure rather than a triple-porosity one (11). The intermediate size of pores, e.g. mesopores, are absent. The remaining scales are the nanoscale and mesoscale. The model will be modified to take into account this different internal structure.

CONCLUSIONS

This work has studied the ability of thin layers of ACFs to absorb sound. The material is easy to handle (high pliability) and lightweight, which makes it a good candidate for silencer or room acoustics applications. ACFs have been described using a multi-scale model that accounts for different scales of porosity. A good agreement has been observed between the model predictions and measurements of sound absorption coefficient for thin layers. However, further improvements need to be done to be able to predict the behaviour of all ACFs presented in this work.

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