Applied Acoustics 115 (2017) 81–87

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

# Approaching a methodology for the development of a multilayer sound absorbing device recycling coal bottom ash

C. Arenas [a,*], C. Leiva [a], L.F. Vilches [a], J.A. González Ganso [b]

[a] University of Seville, School of Engineering, Department of Chemical and Environmental Engineering, Camino de los Descubrimientos s/n, E-41092 Seville, Spain
[b] CIDAUT Foundation (Foundation for the Research and Development in Transport and Energy), Parque Tecnológico de Boecillo, 209, 47151 Boecillo, Valladolid, Spain

ARTICLE INFO

*Article history:*
Received 10 June 2016
Received in revised form 12 August 2016
Accepted 18 August 2016

*Keywords:*
Coal bottom ash
Open porosity
Tortuosity
Airflow resistivity
Acoustic simulations
Sound absorption coefficient

ABSTRACT

The aim of the present work has been to develop a methodology which accurately predicts the acoustic behavior of a material without having to manufacture large panels and testing them in reverberation room. Moreover, it can be predicted the sound absorbing performance at normal and random incidence of the sound wave on a material for different thicknesses and multilayer configurations, dramatically reducing the number of experimental tests. This methodology might decrease the cost of the investigation, which is particularly important when dealing with recycled materials that must compete with commercial products used in the same application.

The designed methodology consists of determining the acoustic intrinsic properties (open porosity, tortuosity and static airflow resistivity) of bottom ash-based concretes with different particle sizes by an indirect method. This method uses the acoustic absorption coefficient measurements obtained in the impedance tube and the mathematical equations that describe the acoustic behavior of porous materials, implemented in the software CARAM. With the intrinsic properties, the thickness of the panel and the vibroacoustic behavior simulation software SIMAM, simulations of the sound absorption coefficient are performed and compared to the experimental results at normal incidence in the impedance tube and at diffuse incidence of a multilayer panel tested in reverberation room.

From the results obtained it can be concluded that the methodology proposed in this work gives accurate results of the acoustic absorption of products at industrial scale, with the advantages of requiring small specimens of the materials to carry out the characterization tests, and decreasing the total cost of the investigation.



## 1. Introduction

Motor traffic is, by far, the most important noise source in developed countries. According to the Spanish General Department of Traffic (DGT), the Spanish car population amounted to 31 million of vehicles in 2014 [1]. One of the main strategies in order to control the traffic noise impact is the use of traffic noise barriers. The European Directive on the Assessment and Management of Environmental Noise [2] have created programs which have promoted the growth in the construction of noise barriers as a way of reducing traffic noise. Reflective barriers are the most frequently used, and they are designed to reflect a large proportion of traffic noise, which creates a problem when a minimization of the sound reflection towards noise sensitive areas adjacent to the highway is required. On the other hand, absorbing barriers are able to reduce the sound intensity reflected in the surface of the wall.

One of the most common materials used for highway noise barrier applications is a combination of porous concrete with a hard backing of standard concrete which increases the mechanical properties of the panel. Porous concrete is made by mixing large aggregate material with mortar, creating lots of voids in the cast concrete. The absorption of the sound results from the dissipation of the sound energy as heat. The dissipation is caused by the energy loss due to flexural vibrations in the specimen, but also due to porosity effects, when multiple reflections of sound waves take place within the voids in the structure [3].

The authors have deeply analyzed the potential recycling of coal bottom ash to develop a porous concrete with good noise absorption characteristic to be applied in the construction of highway absorbing noise barriers [4,5]. Although the use of waste from the energy production of solids fuels as a source of aggregate for the production of porous concrete has become more and more

* Corresponding author.
*E-mail addresses:* cgarcia4@us.es (C. Arenas), cleiva@us.es (C. Leiva), luisvilches@us.es (L.F. Vilches).

http://dx.doi.org/10.1016/j.apacoust.2016.08.021
0003-682X/

common in recent years, very few products developed by researchers at laboratory scale reuse the entire range of particle size of the waste material, neither they have been competitive compared to commercial products used for the same application. One of the reasons for that fact is the need of casting prototypes at industrial scale in order to compare the properties of the recycled products with the commercial versions.

The variety of bottom ash which might be used in this kind of applications has lead the authors to develop a methodology that simplifies the obtaining of a product matrix with sound absorbing properties from coal bottom ash, without discarding any particle size fraction. The mentioned methodology has been developed according to the following steps or stages: (1) the selection of compositions and dosage which develop materials with acceptable sound absorbing properties through the determination of the open void ratio of the product, with the aim of recycling all the particle size of the waste material; (2) the evaluation of the sound absorbing properties of the specimens in impedance tube at laboratory scale; (3) the determination of the relationship between the sound absorbing properties of the products and the thickness of the specimens tested; (4) the manufacture of semi-industrial panels from the composition selected in previous stages and the determination of the acoustic properties in an approved laboratory.

Up until a few years ago, similar methodologies to the one proposed by the authors were followed to design sound absorbing materials with good acoustic behavior. After the manufacture of the material, if the sound absorption measured was not the one expected, the entire process had to be repeated, increasing the cost of the investigation. Nowadays, the acoustic behavior can be predicted by computer programs based on mathematical models and the material intrinsic properties (properties that do not depend on the thickness or geometry). By simulation testing, the sound absorption at normal or random incidence, for different thicknesses and material combinations, can be predicted without the need of carrying out a cumbersome experimental process, and lowering the cost of the project [6].

The vibroacoustic behavior of a material, such as sound absorption, is determined by its microscopic structure. However, due to the complexity of the microscopic structure, which is not homogeneous, the acoustic study is based on its homogeneous macroscopic structure. The macroscopic structure can be characterized by intrinsic parameters which are related to the extrinsic acoustic properties of the material (sound absorption coefficient, acoustic insulation) through mathematical models [7,8]. The intrinsic parameters mentioned are defined as follows:

- Static air flow resistivity, $\sigma$, Rayls/m or N s/m$^4$: it represents the delay by friction, which means the resistance to the quasi-static airflow through the pores of the material. It is defined as:

$$\sigma = \frac{1}{\upsilon}\frac{\Delta p}{\Delta x} \quad \sigma > 0$$

where $\Delta p$ is the pressure variation, $\Delta x$ is the path followed and $v$ is the air flow per unit area.

It gives some idea of the viscous sound dissipation. Air flow resistivity of acoustic materials varies widely from $10^3$ to $10^7$ Rayls/m.

- Porosity, $\phi$, dimensionless: it is the air volume fraction of the material. It is defined as:

$$\phi = \frac{V_{fluid}}{V_{material}} \quad 1 > \phi > 0$$

where $V_{fluid}$ is the air volume (not enclosed in the material cells) and $V_{material}$ is the total volume of the porous material.

- Tortuosity, $\alpha_\infty$, dimensionless: it is a geometrical measure of the deviation between the path followed by the sound wave and the direct path (thickness). It is related to the electrical resistance of a non-conductive porous material saturated by an electrolyte.
- Viscous characteristic length, $\Lambda$, µm: it is the average macroscopic dimension of the cells related to the viscous loss, or the average radius of the smallest pores of the material.
- Thermal characteristic length, $\Lambda'$, µm: it is the average macroscopic dimension of the cells related to the thermal loss, or the average radius of the greatest pores of the material.

In order to completely analyze the use of coal bottom ash as part of recycled concrete for its application as sound absorbing porous material in road traffic noise reducing devices, there is the need to develop a methodology which accurately predicts the acoustic behavior of a composite product, without having to manufacture large panels and testing them in a reverberation room.

The aim of this study has been to estimate the acoustic intrinsic characteristics (porosity, tortuosity, and static airflow resistivity) of the recycled materials developed in previous stages of the investigation, where the entire range of bottom ash particle size was used minimizing the cost of the pre-treatment. Besides that, acoustic simulations were carried out in order to predict the acoustic behavior of a composite multilayer panel manufactured with the bottom ash-based recycled concretes and the results have been compared with those obtained in reverberation room. In this way the need of adjusting several parameters, such as the particle size fraction or the combination and thickness of different layers, is satisfied by using small specimens and therefore, the cost of the investigation is minimized. The work has been carried out in collaboration with the CIDAUT Foundation and has followed the methodological procedures previously described in this section.

## 2. Experimental program

The steps of the methodology proposed in this work are presented in the diagram showed in Fig. 1. The work methodology is

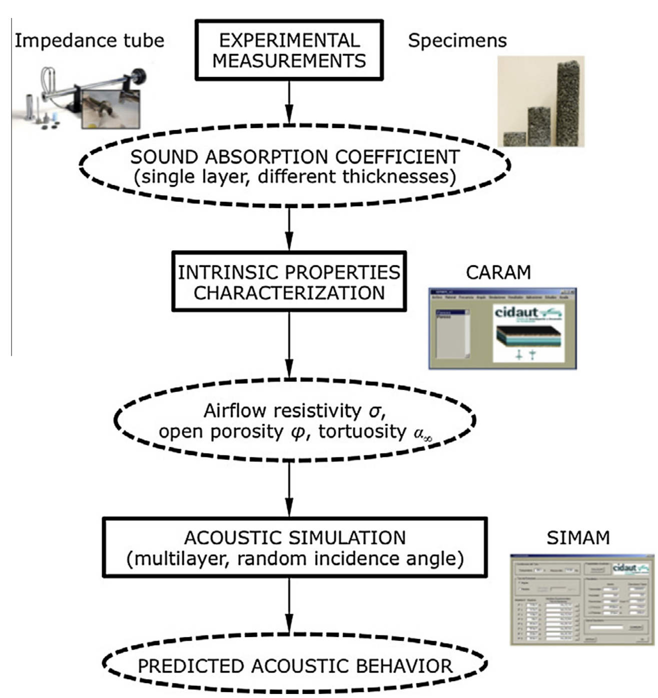


**Fig. 1.** Steps of the methodology for the development of sound absorbing porous materials.