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# Acoustic and mechanical properties of expanded clay granulates consolidated by epoxy resin

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A B S T R A C T

Porous materials were prepared by agglomerating the expanded clay with an epoxy resin with the aim to produce sound absorbers which combine good noise damping performances, excellent mechanical strength and low costs. The use of a polymeric binder, instead of the concrete typically employed in present commercial products, allows obtaining light sound-absorbing panels. In our research the acoustic and mechanical properties of samples of consolidated expanded clay with different thicknesses were experimentally tested. Particularly, the sound absorption properties were measured in a vertical Kundt tube by applying the standing wave ratio method. SEM (scanning electron microscope) observations and porosity measurements were also performed. Experimental results showed a good behaviour with respect to the flexure and compression tests, together with selective sound-absorbing performances and suggest further research opportunities and possible applications of these porous materials as sound absorbers.



## 1. Introduction

A common method to perform noise control is to use a suitable form of sound-absorbing media, e.g. in the form of foams or fibre glass. Unfortunately these materials often lack sufficient structural strength and require expensive protection when exposed to the environment (Vasina et al., 2006). Recently, granular clay has been proposed as an alternative sound-absorbing material since it is safe from the health point of view and it can operate in chemically aggressive environments as well (Magrini and Ricciardi, 2000).

The advantages of using the expanded clay relate to its very light mass combined with a relatively high structural strength, high physical–chemical stability and low cost. The light mass of this product is largely attributed to a relatively high proportion of semi-closed pores which can account for up to 90% of the particle volume. This material is typically manufactured from bloating clays which, upon firing, expands or bloats into a frothy mass with a high proportion of semi-closed pores. The porous structure of the loose expanded clay granulates is formed by the voids among the individual grains and by the pores in the grain base. From the acoustic point of view this material offers the possibility of developing porous structures whose acoustic performance benefits from an extensive network of macropores created among the individual grains. Additional micropores, which are inherited by the grains from the firing process, are also able to contribute to the acoustic performance increasing the overall porosity of the granular mix (Asdrubali and Horoshenkov, 2002).

In literature the acoustic absorbance of the expanded clay and its ability to be selective for different frequencies of the acoustic waves were deeply discussed (Bartolini et al., 2002; Voronina and Horoshenkov, 2004; Vasina et al., 2006). The advantageous narrow-band noise reduction induced by the granular materials can be exploited to enhance the noise attenuation. Besides, the inert granular materials exhibit a high resistance to the noise-induced fatigue that consists in the disintegration of the sound-absorbing material due to a prolonged exposure to pressure waves.

Actually, the use of granular clay as a sound absorption material requires grids to contain and sustain the granulates. This aspect can represent a limit for a wide application in industrial noise control.

To increase both the structural strength and the durability of granular materials eliminating the use of grids, some procedures of agglomeration by adding cementitious binders were proposed, leading to several commercial products (e.g. SoundSorb, Whiper Wall Spund Absorbing System) (Laukaitis, 1997a,b; Horoshenkov et al., 2003; Umnova et al., 2003; Marolf et al., 2004; Neithalath et al., 2004; Tiwari et al., 2004).

The substitution of the cementitious binders with the polymeric ones (lighter than concrete) should guarantee the structural strength to the final product, leading to a lighter system characterised by a quite open structure. The main goal of the present research was to prepare new expanded clay agglomerates based on a polymeric binder and to test their acoustic and mechanical properties.

Studied composite materials can be used to realise self-sustaining panels or thick coating for the noise control. By means of the new

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proposed technology several products can be developed: baffles, to reduce reverberation in large rooms or to be used in manufacturing of dissipative mufflers, and linings, for air ducts with the aim of reducing the transmission of sound along. Such new composite material could, in general, replace glass and mineral wool, commonly used as lining, because it is considered to be more acceptable from the health point of view and better suited to operate in an aggressive environment.

The binder selected to produce the composites was an epoxy resin, that allows to optimise the characteristics of light mass, compactness, mechanical resistance and low cost in the final porous systems. Epoxy resins are thermosetting polymers of wide application and versatility thanks to their cross-linked structure (Rozemberg, 1986; Allen and Bevington, 1989); they should ensure to the final products high chemical, thermal and mechanical resistance, not flammability and remarkable sound absorption properties.

In the present work the mechanical and acoustic behaviour of the clay–epoxy composites were experimentally assessed to verify their applicability as sound absorbers. The characteristics of the loose expanded clay were used as terms of comparison.

The clay–epoxy composites were realised keeping in mind the most important physical properties which influence the sound-absorbing behaviour of porous materials: porosity, tortuosity, density and particle dimension of the granular material (Asdrubali and Horoshenkov, 2002): the granule size has a remarkable effect on the acoustic performance, namely on the sound absorption coefficient, by producing variation of the flow resistance in porous materials (Horoshenkov and Swift, 2001). Vasina et al. (2006) found that good absorption performances were achieved when the characteristic particulate dimension of the aggregate was kept below 3.5 mm.

The sample thickness strongly influences the acoustic properties, by depending on the normalized frequency (Voronina and Horoshenkov, 2004). The normal incidence absorption coefficient varies with the frequency in a different way according to the ratio between the fundamental natural frequency and the characteristic frequency of the material.

## 2. Experimental

### 2.1. Materials

The inert material was the “Leca” expanded clay supplied by “Laterlite” (Milan, Italy). It was characterised by:

- Light mass, due to the particular cellular structure included in a rigid shell that allows to balance the mass with the mechanical resistance.
- Resistance to the fire, since it was heated at 1200 °C during the firing process.
- Compression resistance ($\sigma \cong 2.5$ N/mm$^2$), due to the dense external structure.
- Weathering resistance. Due to the heating at 1200 °C, the expanded clay does not contain any organic material; thus it does not suffer any degradation over time for different conditions of temperature and relative humidity.
- Thermal insulation (the thermal conductivity is equal to 0.1 W/m K and remains unaltered over time).

This material was commercially available in different size ranges (0–2 mm; 2–3 mm; 3–8 mm; and 8–20 mm); each fraction contained granulates of different dimensions and shapes. On the basis of previous research (Horoshenkov and Swift, 2001; Bartolini et al., 2002), 2–3 mm size range material was chosen for its interesting acoustic properties in terms of sound absorption.

To characterize this system, with particles of different shape, a “particle characteristic dimension” was defined as the diameter of a sphere which volume is equivalent to the mean volume of the particles (Voronina and Horoshenkov, 2004):

$$D_c = \sqrt[3]{\frac{1.91V}{N}}$$

where $N$ indicates the number of the particles in a unit volume $V$ expressed in cubic millimetres. The average characteristic dimension of the particles was equal to 3.5 mm, close to the optimum values range obtained by Vasina et al. (2006) for sound-absorbing performance of this class of porous media.

The polymeric binder was synthesised from the reaction between the epoxy resin D.E.R. 332 (Bisophenol A diglycidyl ether, BADGE), purchased by Fluka, and the cross linking agent, diethylenetriamine (DETA) (purity of 99% and density 0.955 g/ml), supplied by Aldrich. The mass ratio between BADGE and DETA was kept equal to 87/13 throughout all the experiments (Pedemonte et al., 2006).

### 2.2. Specimen preparation

The shape and dimensions of samples were varied for the different measurements. Particularly, cylindrical samples (Fig. 1) of different thicknesses (50, 75, 100 and 125 mm) were prepared for the acoustic characterisation and squared samples for the mechanical analysis.

As shown in previous experiments, the best mass ratio between the expanded clay and the polymeric binder was 90/10, as it guaranteed a good compromise of the mechanical and acoustic characteristics, maintaining the low cost.

Firstly, the expanded clay was mixed with the epoxy resin to get a homogeneous system: all the grains had to be completely covered by the binder. The clay–epoxy resin was introduced into the PVC mould (cylindrical or squared) and slightly consolidated till the upper surface was roughly plain. The mould was internally covered with oleophobic paper, sprinkled with silicon oil to prevent any sticking and to allow the sample extraction after curing. The complete curing process was performed for 48 h at 60 °C.

### 2.3. SEM observations

Morphological observations were carried out with a Scanning Electron Microscope Stereoscan 440 Leica-Cambridge associated with an EDS (energy dispersive spectrometry) microprobe Link-Gun Oxford, after covering the specimen with a very thin layer of graphite to obtain a good conductivity. Slides of the loose and consolidated clay samples were obtained by blade cutting under an optical microscope.

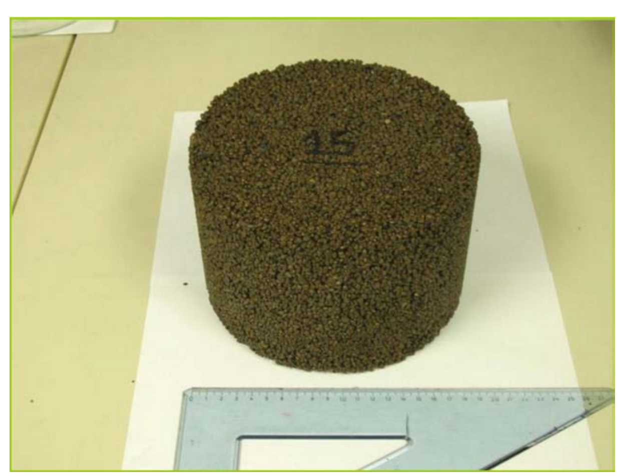


**Fig. 1.** Cylindrical samples of clay–epoxy composites for acoustic characterisation.