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A NEW SOUND INSULATION LIGHTWEIGHT CONCRETE MASONRY BLOCK. DESIGN AND EXPERIMENTAL CHARACTERIZATION

H. Sousa[1]; A. Carvalho[2]; A. Melo[3]

Abstract

The purpose of this paper is to present an innovative design approach for a sound insulation lightweight concrete masonry unit made with expanded clay *LECA®*.
This block is especially developed and suited for sound insulation between dwellings and presents an airborne sound insulation that allows realizing separating walls between different houses quicker and with lower costs.
In the design phases different walls solutions and block geometry have been studied and tested to define the optimum solution. After the stabilization of the unit masonry geometry, a deep characterization of block and final walls has been made. The experimental work includes acoustical, physical and mechanical properties of the blocks and walls. A synthesis of this work is presented.

Key Words

Masonry, block, sound insulation, lightweight concrete.

1 Introduction

Masonry is a common component with low cost, low maintenance, good durability and aesthetics and can be used exploring its acoustic properties.
The use of masonry units as sound absorber or sound isolators is increasing on buildings applications or as sound barriers along roads.
One of the raw materials that can be used in masonry units is the lightweight concrete. Lightweight concrete blocks are a good masonry material because they are lighter and easier to lay than standard concrete blocks. Otherwise they can have good behaviour under thermal and mechanical points of view.
At the moment there is, in Portugal, a lightweight expanded clay aggregate factory belonging to a world leader in the production of these aggregates. The aggregates are used mainly in light infilling and precasting of lightweight concrete products.
Nowadays almost 10 % of the 220 factories of vibrocompressed products existents in Portugal use lightweight expanded clay aggregates in their products. Between these

[1] Hipólito Sousa, Fac. Engineering of Porto University, hipolito@fe.up.pt.
[2] A.P. Oliveira Carvalho, Fac. Engineering of Porto University, carvalho@fe.up.pt.
[3] António Fontes Melo, Pavileca – Factory of Maxit Group, fontes.melo@pavileca.pt.

products the most important are the masonry blocks. The most frequent applications are:

- building enclosures, using multichamber blocks, normally with thickness equal or greater than 0.25 m, used in single leaf walls, with or without thermal insulation, because they have a good thermal behaviour. The acoustic insulation is also good. The mechanical resistance is low, and the structural utilization is limited to small buildings;
- internal partition walls, according to the light character of the units;
- walls of industrial, store and agricultural buildings;
- freestanding masonry boundary walls.

The authors have already designed an absorvative lightweight concrete block that is now used in many applications throughout the country, Fig.1 (Sousa and Carvalho, 1998).

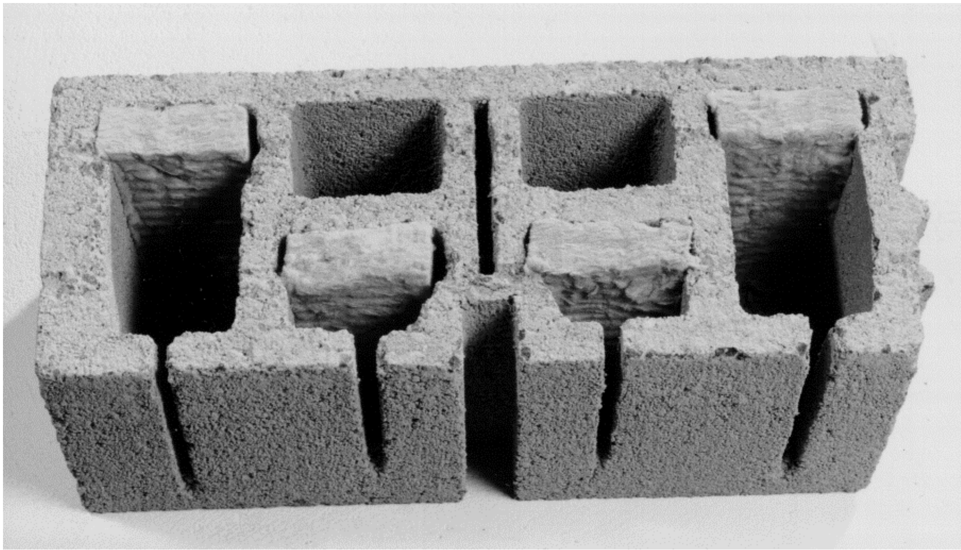


Figure 1 Photograph of a new sound absorbing lightweight concrete sound absorbing masonry block

A Portuguese manufacturer of lightweight concrete products-PAVILECA, S.A, challenged again the Faculty of Engineering of Porto University to develop a new lightweight concrete masonry block for improved sound insulation between dwellings.

Nowadays infilling walls used between dwellings are generally ceramic units in cavity walls, with acoustical material in the middle according to standard requirements.

The aim of the lightweight concrete masonry block manufacturer was to have a single wall, easier and quicker to lay, without acoustical insulator and more economic.

Under an acoustic point of view there are two different areas of analysis related to its acoustic behaviour:

- sound isolation;
- sound absorption.

The sound isolation in single walls is fundamentally function of the known mass law. Several studies in different countries allow to say that masonry made with lightweight concrete units, if conveniently plastered to be airtight, has a better behaviour than the suggested by the mass law (Short and Kinniburgh 1978, Cormon 1973).

Sound absorption is a different property and is related with the decreasing of sound reflection from a surface. Most lightweight concrete surfaces, if unplastered, have a quite good sound absorption.

The work began with an experimental sensitive analysis of the acoustic insulation of different walls to understand the influence of different factors. With these results the development of the new block geometry takes care of the following aspects:

- concrete as raw material;
- acoustic requirements;
- geometric and dimensional requirements;
- mechanical requirements;
- laying requirements;
- production technology requirements.

After the production of the new block a complete experimental analysis has been made to define the properties and behaviour of the blocks and the wall.

2 Product conception approach

2.1 Concrete

The production of concrete for the manufacture of masonry units is very different of other concretes. The quantity of cement is the minimum to achieve adequate strength, to minimize the cost and to limit shrinkage.

The amount of water is very low to make possible to extrude blocks immediately after moulding without slump. Those particularities are yet more specific for lightweight concretes. The grading and mechanical resistance of the aggregates, the particles' shapes, the type of block machine, the mix proportions and the curing process are also very important factors for these concretes. Generally in lightweight products the concrete has lightweight aggregates, but also standard aggregates to achieve a minimum mechanical resistance according that the blocks have a relevant volume of voids. A mix design method for these types of concrete, for factories of precast products of lightweight concrete that allows defining mix proportion and related properties has been developed in another research study (Melo 2000).

The blocks ought to be done with one of the lightweight concrete composition used by the manufacture in their products. The block ought also to respect some technical constraints in the fabrication process. It was decided to select the concrete used in current lightweight blocks with the following mix proportions, Table 1.

Table 1 Mix characteristics of the lightweight concrete

Products	Quantities
Portland cement	- 200 kg/m^3
Dense sand	- 0.530 m^3/m^3
Fine “Leca” aggregate (2/4 mm)	- 0.140 m^3/ m^3
Medium “Leca” aggregate (3/8 mm)	- 0.730 m^3/ m^3
Water	- 0.070 m^3/ m^3

The characteristics of this concrete are presented in Table 2.

Table 2 Characteristics of the lightweight concrete

Dry density (kg/m^3)	Compressive strength at 28 days (MPa)	Modulus of elasticity (MPa)	Bending tensile strength at 28 days (MPa)	Thermal conductivity (W/mºC)
1 250	9.3	11000	2.6	0.50

2.2 Acoustical requirements and sensitive analysis

The new Portuguese Noise Code for Buildings (DL 129/2002) requires that the walls have a minimum airborne sound insulation (controlled by its weighted normalized level difference Dn,w according with EN140-4 and 717-1) as stated in Table 3.

A previous experimental analysis was done by testing in situ six wall solutions to compare their relative ability for sound insulation. Single and double walls made with lightweight concrete and with ceramic bricks were tested using a 3.00x5.85 m2 wall. The acoustic results showed a favourable effect in the lightweight concrete blocks' double wall to the ceramic bricks (if corrected for identical weight). These results were optimistic and gave the authors several clues in the research to a good and competitive solution.

Table 3 Minimum weighted normalized level difference (Dn,w) for building walls according to (DL 129/2002)

Situation	Dn,w ≥ (dB)	Dn,w - 3 *≥ (dB)
Between dwellings	50	47
Between dwellings and public service areas of the building	48	45
Between classrooms	45	42
Between classrooms and hallways	50	47
Hospitals (between rooms)	45	42

* The Portuguese Code allows for a 3 dB margin to take into account measurement uncertainties

2.3 Dimensional and geometric requirements

The external dimensions of the units should respect modular co-ordination size principles. In Portugal the current co-ordinations sizes of blocks are:

- 500 mm (length) x 200 mm (height) x e (thickness);
- 400 mm (length) x 200 mm (height) x e (thickness).

Usually the current thickness - ***e*** - of blocks is multiple of 50 mm. In this case as we want to develop an alternative solution to the current solution (cavity wall with sound insulation in the cavity and total thickness of 250 mm before finishes) we should have a thickness not higher than 250 mm.

The co-ordination size of 400 x 200 x 250 mm^3 has been selected, according the need to limit the weight of the units.

The work size, as the specified dimensions for the manufacture of the unit, is obtained for the co-ordination size reduced of the mortar joints thickness. In this case there is mortar on the horizontal bed joints and in perpend joints in the full height on pockets with a minimum of 40% of the width of the unit, the external dimensions of the blocks are:

- 400 mm (length) x 190 mm (height) x 200 mm (thickness)

The specified permissible deviations according European standards (prEN771-3, 1999) are:

- +3 mm or -5 mm on length, thickness and height.

Regarding geometric requirements the next requirements have been identified:

- the block should be as symmetric as possible in longitudinal and transversal directions, for a easier laying;
- the convenience that the block geometry has some break at its axis that materialize the boundary between the neighbours dwellings;
- the quantity of lightweight concrete must be limited so far as the production cost is proportional to this quantity and the cost of transport and laying increases with the weight.

2.4 Mechanical requirements

The lightweight concrete used in the production of these blocks has a low compressive strength. This low value is related with the density of the concrete, the Portland cement content and, fundamentally, with the resistance of the expanded clay aggregates.
Although this kind of blocks is not suited to resistant walls, they must be stable to several actions and have adequate mechanical resistance.
The minimum individual value of the compressive strength of the units shall be not less than 3.0 MPa. The compressive strength is expressed as the maximum crushing load of the specimen divided by the apparent external area, corrected by a shape factor that converts the compressive strength to a normalized value.
Another requirement is the need to limit the relative high drying shrinkage of the lightweight masonry blocks. The practical result of shrinkage is the development of dimensional constraints that allows to tensile stresses with cracking results. Is important that drying shrinkage magnitude does not exceed a reasonable value, and to store blocks enough time before laying to ensure that they are almost dry when used. In stock they must be keep out of rain.
The limit concerning long term shrinkage in conventional situation according NF standard (NFP 14-304 1983), has been established to internal control in 450 x 10^{-6} m/m.

2.5 Laying requirements

There are no special laying requirements for this kind of blocks. Has been decided that a current mortar should be used and the horizontal joint should be interrupted. In terms of vertical joints they should be filled by acoustical reasons, preferably in pocket joints to an easier laying.

2.6 Production technologies requirements

As known, the production of concrete blocks, and particularly lightweight concrete blocks, differ from current structural concrete. The block production is compacted in a different way and requires a “green” strength to be demolded after forming and being handled and transported immediately. The control of the grading and the quantity of water mix is of vital importance, to the better vibration and compacting.
A high efficiency mixer with volumic control of aggregates and water and weight control of cement is supposed to be used in production. The blocks machine is stationary, fully automatic, and with high-speed. The machine distributes the fresh concrete into a mould, compact it on a flat pallet, ejects the molded block and repeats the cycle.
The fresh blocks on the pallets are automatically transported to curing chambers where they stay some hours air-curing or steam-curing depending of the atmospheric temperature. After curing on the chambers the blocks are packed and stored for complementary curing.

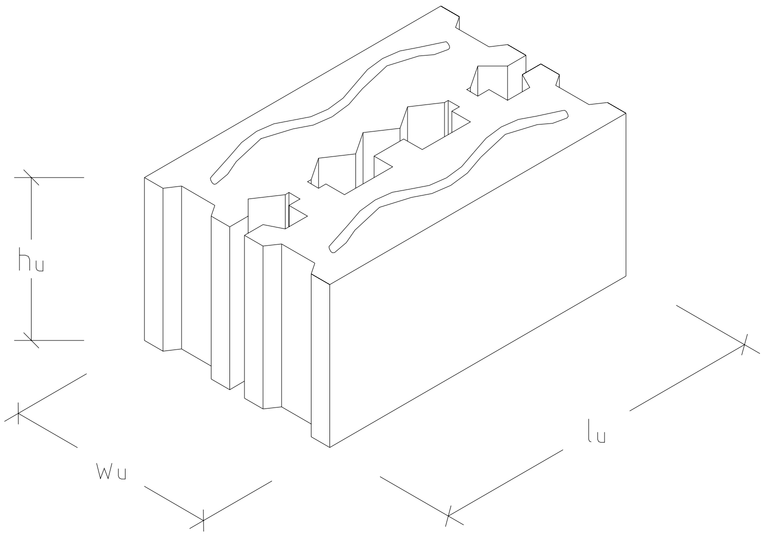
3 Results

After the analysis of the requirements to achieve the intent three possibilities of solution could be adopted, Table 4.
The third solution has been adopted and the block is presented in Fig. 2.

Table 4 Comparison between the different solutions for the sound insulation improved blocks

Solution	Advantages	Disadvantages
Units without holes with mass greater than 250 kg/m3	Simple solution Good mechanical resistance	Low optimization High cost The propriety limit between

	Good productivity in laying	dwellings is not materialized
Units with holes, made of two equal parts linked by a flexible and insulating material	Innovative Materialize the boundary between proprieties Acceptable costs	Production technology complicated Unit breakable Sustainability of the insulation material
Equal to the previous but the with the linkage made in the same concrete of the units	Moderate innovation Easy production technology Low cost	The link decrease the acoustic insulation Unit with a fragile link



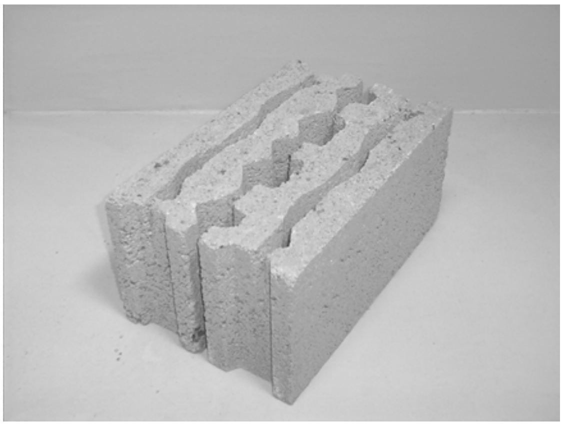


Fig 2 Schematic view and photo of the final block

4 Performance

4.1 Units performance

After the stabilization of the unit masonry geometry, a characterization of block and walls has been initiated. The experimental results available are presented in Tables 5 to 6.

Table 5 Dimensions, percentage of voids and density of blocks

Values	Dimensions (EN772-16, 2000) (mm)			Percentage of voids (EN772-9, 1998) (%)	Net and dry density (EN772-13, 2001) (kg/m^3)
	Length	Height	Thickness		
Medium	400.8	192.2	250.4	21.8	1147
Minimum	400.4	191.8	250.0	21.6	1073
Maximum	401.2	192.6	250.9	22.3	1273

Table 6 Moisture content, water absorption and compressive strength of blocks

Values	Moisture content referred to the dry mass (ASTM C140, 1991) (%)	Water absorption		Compressive strength (EN 772-1,2000) (N/mm^2)
		By immersion (ASTM C140, 1991) (%)	By capillarity (EN 772-11, 2000) (g/ (m^2.g^{0,5}))	
Medium	1.9	11.4	176	4.70
Minimum	1.5	10.0	144	3.81
Maximum	2.2	12.2	213	6.45

4.2 Walls performance

The behaviour of the walls is now under test. At the moment are available the acoustic results. This type of block was tested in laboratory using a reverberant chamber (according to EN 140-3 1998 and EN 717-1 1996) to measure the weighted sound reduction index of the wall, Rw. A general purpose mortar pre-batched has been used in joints and wall render. The results found are presented in Table 7.

Table 7 Block characteristics (Lab. measurements)

Situation	Rw (dB)	Rw - 3 * (dB)
Lightweight block	53	50

* Predicted Dn.w in usual situations (taking into account the flanking transmissions)

Are also foreseen mechanical tests of the walls, evaluation of the influence of chases, stability under chocs and analysis of costs including laying productivity.

5 Conclusions

The study showed that is possible to achieve an optimised sound insulation between dwellings using a lightweight concrete single block, instead of using the Portuguese traditional ceramic brick double wall.

The block is now under a serial of experimental tests, but the already available results indicate that it complies with the applicable legal and technical requirements concerning masonry walls.

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