LIGHTWEIGHT CONCRETE FOR MASONRY BLOCKS EXPERIMENTAL CHARACTERIZATION AND A PROPOSAL OF MIX DESIGN METHOD

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ABSTRACT

The use of infilling masonry units made with expanded clay lightweight concrete is increasing in Portugal. There are not too many studies concerning these specific types of concrete to be used in vibrocompressor system productions.

In this paper the results of an experimental study are presented for different lightweight concrete masonry products, with samples obtained on real production conditions. For concrete densities between 850 kg/m^3 and 1450 kg/m^3, different properties of these types of concrete, like compression and tension strength, modulus of elasticity, shrinkage, water absorption by capillarity and immersion and thermal conductivity are presented and related.

A mix design method for these concretes, developed for factories of precast products of lightweight concrete, that allows to define mix proportion and related properties is presented too.

NOTATION

A	=	Faury parameter related with the nature and shape of the aggregate and the vibration energy
B	=	Faury parameter depending of workability
D	=	Maximum aggregate size
I	=	Voids index of a compact concrete including water added
K	=	Faury parameter related with the nature and shape of the aggregate and the vibration energy
K’	=	Faury parameter depending of workability
R	=	Mould medium radius, related with wall effect (quotient of the volume of concrete by the surface of the mould)
d_1	=	Greatest size of the sieve were is a retained fraction
d_2	=	Next sieve to d_1
p_1,..p_n	=	Percentage of aggregates *1, …, n* in the mix
m_0	=	Fineness modulus of reference curve
m_1,…m_n	=	Fineness modulus of aggregates *1, …, n*
x	=	Percentage by mass of aggregate retained on sieve d_1
y	=	Percentage by mass of aggregate retained on sieve d_2

1. INTRODUCTION

1.1. Brief presentation of Portuguese masonry situation

In present days in Portugal the major buildings structures are in reinforced concrete frames. Other solutions, like masonry structures, are seldom used and normally in small one family houses.

In the middle of the XX century the importance of rain watertightness, associated to the thickness and weight wall reduction, led to the generalization of cavity walls that is the most frequent solution in Portugal presently. Normally the walls have thermal insulation in the cavity [1].

Usually all types of walls were covered with traditional renders to be painted. At the moment alternative solutions have significant expression, according the tentative of reduce maintenance costs and to get skill workers to finish renders:

- cladding of ceramic tiles and thin stone plates glued or fixed to a first layer of render;
- use of readymix mortar with pigments render materials – single coat;
- cavity walls with facing units;
- thin synthetic render, reinforced with glass fiber mesh, beside thermal insulation.

The most popular masonry materials are the clay units, large horizontally perforated, used on enclosure and internal walls[2]. The other materials also used are:

- clay units solid or vertically perforated (facing bricks or not), used only in external walls;
- aggregate concrete units, dense or lightweight, used more in external walls;
- natural stone, which use is limited to some small regions.

Some new materials, not traditional, have a residual application:

- autoclaved aerated concrete units;
- split dense aggregate concrete units;
- lightweight clay units, vertically perforated;
- special shape units.

Generally these new products are well developed and studied, but their cost is yet higher than traditional ones.

Concerning lightweight concrete, in the beginning of the 90’s the unique Portuguese lightweight expanded clay aggregate factory has been acquired by an industrial group, world leader in the production of these aggregates. At the moment these aggregates are used mainly in light infilling and precasting of lightweight concrete products (Figure 1).

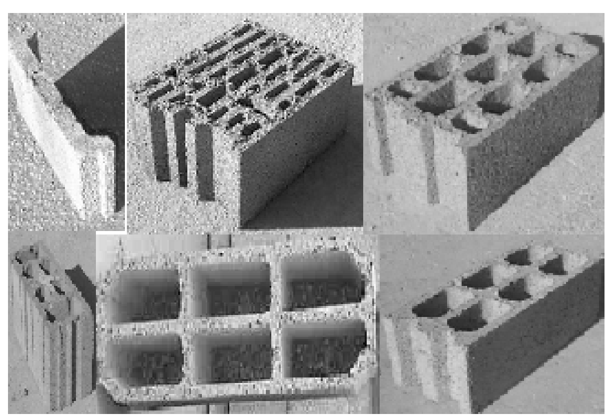

Figure 1-Examples of precast products made with lightweight concrete

Nowadays almost 10 % of the 220 factories of vibrocompressed products existents in Portugal use lightweight expanded clay aggregates in their products. Between these products the most important are the masonry blocks [3]. The most frequent applications are:

- building enclosure, using blocks multichamber, 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.

1.2 Specifities of lightweight concrete for masonry blocks

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 normally 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 normal aggregates to achieve a minimum mechanical resistance according that the blocks have a relevant volume of voids.

1.3 Scope of the work

As referred in 1.1 the employ of lightweight concrete of expanded clay in precast products for construction, like current and special masonry units and also floor units for slabs is growing.

A more deep knowledge concerning the specificities of these concretes is needed to a better design and optimisation of the characteristics of these products.

With this purpose an experimental study relating mix design and principal properties of expanded clay lightweight concretes with densities between 850 kg/m^3 and 1450 kg/m^3 has been realized involving the main factory of these products and the Faculty of Engineering of Porto University.

2. MIX DESIGN METHOD FOR LIGHTWEIGHT CONCRETE FOR MASONRY BLOCKS

The aim of the concrete mix design for lightweight concrete, selected the components to be used, is to define the cement quantity, the proportion of each aggregate, the relation water/cement and the eventual utilization of adjuvants, as is normal for the generality of concretes, but also to relate these quantities with the density of the concrete needed and expected, that is the main difference for normal concretes [3]. As known in lightweight concretes the most important properties (like mechanical resistance, thermal insulation, shrinkage…) are related with concrete density.

The concretes to be used in vibrocompressed products, like masonry blocks, have also some specifities that are not presented by normal concretes:

- the very strong vibration that the products are subjected;
- the workability associated to a damp soil concrete, with a water content approximately of 8% of the mass of the green concrete;
- the wall effect, according that the surface of contact with the mould is very high and the volume is low.

In Portugal the grading of coarse and fine aggregates, normal or lightweight, has not standard limits for any kind of concrete. In the mix design of normal structural concretes methods of reference curves are normally used. One of the most popular methods is the Faury grading combined aggregates and cement curve, that includes the influence of the vibration conditions, the shape of the material and the wall effect in the demand of the maximum compacity, (Figure 2).

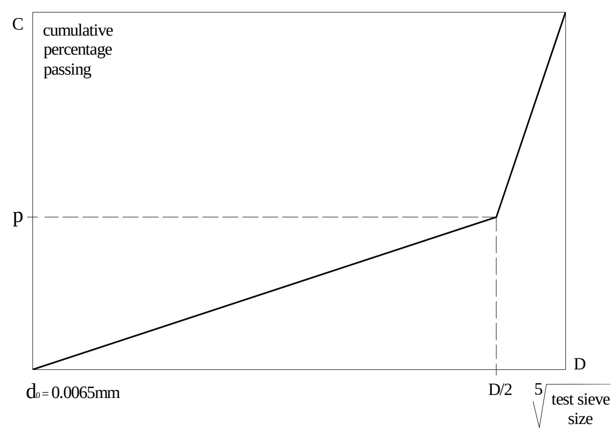

Figure 2-Faury reference curve

$$p_{D/2} = A + 17\sqrt[5]{D} + \frac{B}{\frac{R}{D} - 0{,}75} \quad (1)$$

$$D = d_1 + (d_1 - d_2)\frac{x}{y} \quad (2)$$

$$I = \frac{K}{\sqrt[5]{D}} + \frac{K'}{\frac{B}{D} - 0{,}75} \quad (3)$$

Although we do not know any references to mix design methods applied to lightweight concrete for masonry blocks, it seems to be possible to apply the Faury method searching the maximum compacity for a group of aggregates and for some real conditions of consistency and vibration. As for these concretes the density is previously defined, this is an additional condition to the problem.

We can resume the mix design in the following conditions:

- the sum of the aggregates in the mix should be 100%

$$p_1 + p_2 + \ldots p_n = 100\% \quad (4)$$

- the fineness modulus of the mix should be the nearest of the reference curve

$$m_1 p_1 + m_2 p_2 + \ldots m_n p_n = m_0 \quad (5)$$

- the medium quadratic deviation between the reference curve and the mix curve should be the minor;
- the adjustment of concrete density can be achieved replacing a light aggregate for a normal aggregate with the same grading or contrariwise [3].

3. THE EXPERIMENTAL STUDY

3.1. Planning

According the planning it was decided to characterize the lightweight concretes more used for masonry blocks industries, with densities between 850 kg/m^3 and 1500 kg/m^3.

Seven mix design group corresponding to different densities have been selected and for each one four quantities of cement (Table 1).

The materials used in the mixes are:

- One coarse lightweight aggregate of expanded clay – LECA 4-10;

- One fine lightweight aggregate of expanded clay – LECA 0-2;
- One coarse normal aggregate (crushed granite)– 4-10;
- One fine normal aggregate (granitic sand);
- Portland cement.

Table 1
Mix design adopted

Mix Ref.	Cement (kg)	LECA 4-10 (%)	LECA 0-2 (%)	Normal coarse aggregate (%)	Normal Sand (%)	Expected density (kg/m^3)
D1A	126	70	20	-	10	853
D1B	155	70	20	-	10	853
D1C	185	70	20	-	10	853
D1D	214	70	20	-	10	853
D2A	126	70	10	-	20	960
D2B	155	70	10	-	20	960
D2C	185	70	10	-	20	960
D2D	214	70	10	-	20	960
D3A	126	70	-	-	30	1067
D3B	155	70	-	-	30	1067
D3C	185	70	-	-	30	1067
D3D	214	70	-	-	30	1067
D4A	126	65	-	5	30	1155
D4B	155	65	-	5	30	1155
D4C	185	65	-	5	30	1155
D4D	214	65	-	5	30	1155
D5A	126	60	-	10	30	1243
D5B	155	60	-	10	30	1243
D5C	185	60	-	10	30	1243
D5D	214	60	-	10	30	1243
D6A	126	55	-	15	30	1330
D6B	155	55	-	15	30	1330
D6C	185	55	-	15	30	1330
D6D	214	55	-	15	30	1330
D7A	126	50	-	20	30	1418
D7B	155	50	-	20	30	1418
D7C	185	50	-	20	30	1418
D7D	214	50	-	20	30	1418

The characteristics of the concretes that have been evaluated are those referred below (Table 2).

The tests respected the Portuguese standards applicable. The specimens have been produced in one of the factories machine in the same conditions in which the masonry blocks are produced. This is the unique way to assure that the concrete is similar and compacted by the same way (Figure 3). This option obliges to produce a special machine mould and to adjust some specimen dimensions to these conditions (Figure 4).

3.2. Aggregates and Cement characteristics

The lightweight expanded clay aggregates used in the study are from Portuguese "LECA" factory, produced in a rotatif oven. The normal aggregates are currents in the north of Portugal, the sand from"dune sand" and the coarse aggregate from granitic stone – quarry.

The synthesis of the characteristics are presented in Table 3

The Portland cement is a II 42,5R according Portuguese and European standards NP EN 196.

Table 2
Tests and specimens

Test	Specimen dimensions [1] (m)	Number of specimens for each mix
Dry bulk density	Cilindre D= 0,10 H= 0,20	6
Compressive strength	0,20x0,20x0,20	6
Flexural strength	0,10x0,70x0,20 (*t* x *l* x *h*)	3
Modulus of elasticity	0,10x0,10x0,30 (*t* x *l* x *h*)	3 [2]
Shrinkage	Cilindre D= 0,10 H= 0,20	2 [3]
Water absorption by capillarity	0,10x0,10x0,20 (*t* x *l* x *h*)	1 [3]
Water absorption by immersion	0,10x0,10x0,30 (*t* x *l* x *h*)	1 [3]
Steady state thermal transmission	0,30x0,30x0,05 (*t* x *l* x *h*)	2 [2]

[1] - t – thickness; l – length; h – height
[2] – made for 7 selected mixes
[3] – made for 3 selected mixes

Figure 3- Machine used to produce specimens

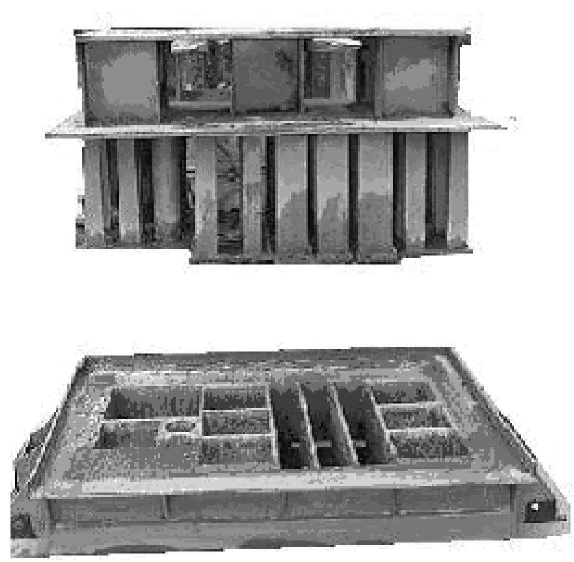

Figure 4-Mould used to produce specimens

Table 3
Aggregates characteristics

Characteristics	Coarse aggregates		Fine aggregates	
	Lightweight "LECA 4-10"	Normal "Brita 4-10"	Lightweight "LECA 0-2"	Normal "Dune sand"
Dry real density (kg/m^3)	540	2730	1320	2660
Loose bulk dry density (kg/m^3)	330	1420	660	1510
Compacted dry bulk density (kg/m^3)	350	1540	730	1650
Crushing resistance (N/mm^2)	1,04	-	-	-
Current moisture content in production conditions (%)	27,7	3,8	31,0	5,3
Fineness modulus	5,27	5,17	2,58	1,87
D- Maximum aggregate size (mm)	10,06	8,04	2,42	1.19

3.3. Specimens production and curing

All the specimens have been produced in the same day and in the same conditions, with the same aggregates. All the industrial systems have been previously calibrated. The mixer has an automatic system to adjust water added considering the aggregates moisture.

The vibration parameters and the moulding time have been equals too.

The workability of the fresh concrete has been evaluated with Vebe test and the results are of a rough and without cohesion concrete.

The cure conditions of these specimens are the current for vibrocompressed products. First eight days in a cure chamber at 14ºC and 90% HR, after this period of time the specimens stayed in a covered store without temperature and humidity conditioning, except for the specimens used in test where the temperature and humidity conditioning is necessary.

4. RESULTS

The comparison between the expected and effective dry bulk density for the different concretes, as well as the compressive and flexural strength and the elasticity modulus at 28 days are presented (Table 4). The evolution of the compressive strength with the time has been determined between 1 and 160 days and is presented (Figure 5) for mix references D1B, D4B, and D7B.

Table 4
Density and resistance of lightweight concretes

Mix Reference	Dry bulk density			Compressive strength		Flexural strength		Modulus of elasticity	
	Expected	Real	Deviation	Mean value	Variation coefficient	Mean value	Variation coefficient	Mean value	Standard deviation
	(kg/m^3)	(kg/m^3)	(%)	(N/mm^2)	(%)	(N/mm^2)	(%)	(N/mm^2)	(N/mm^2)
D1A	853	836	-2.0	5,93	2	1,38	8	-	-
D1B	853	836	-4.2	5,63	6	1,49	10	5400	0,5
D1C	853	908	1.8	6,79	4	1,61	9	-	-
D1D	853	871	-5.0	5,39	15	1,76	2	-	-
D2A	960	870	-7.9	5,49	4	1,49	6	-	-
D2B	960	919	-4.2	5,53	7	1,35	21	6800	1,5
D2C	960	939	-4.6	6,26	9	2,07	7	-	-
D2D	960	1003	0.6	6,56	9	2,06	8	-	-
D3A	1067	988	-4.1	5,13	12	1,44	12	-	-
D3B	1067	950	-10.5	6,93	6	1,84	8	7900	0,9
D3C	1067	985	-8.3	6,80	12	2,24	7	-	-
D3D	1067	1096	1.0	8,19	9	2.40	14	-	-
D4A	1155	1035	-9.1	5,95	11	1,73	16	-	-
D4B	1155	1240	7.4	6,90	5	1,64	7	8800	1,3
D4C	1155	1199	2.8	7,48	7	2,23	8	-	-
D4D	1155	1136	-4.0	8,62	8	2,42	3	-	-
D5A	1243	1157	-4.5	6,65	7	1,80	6	-	-
D5B	1243	1209	-1.4	6,69	8	2,21	9	10300	1,6
D5C	1243	1178	-5.4	8,31	9	2,26	17	-	-
D5D	1243	1311	4.0	9,27	6	2,58	3	-	-
D6A	1330	1229	-7.9	5,83	13	1,78	11	-	-
D6B	1330	1285	-4.4	8,52	7	2,19	4	14700	2,9
D6C	1330	1312	-3.4	8,79	8	2,67	6	-	-
D6D	1330	1367	-0.4	10,64	4	2,68	6	-	-
D7A	1418	1330	-6.9	6,17	15	2,02	9	-	-
D7B	1418	1458	1.5	8,92	8	2,38	14	13500	1,6
D7C	1418	1443	-0.3	11,62	4	2,55	8	-	-
D7D	1418	1487	1.5	11,70	5	2,81	10	-	-

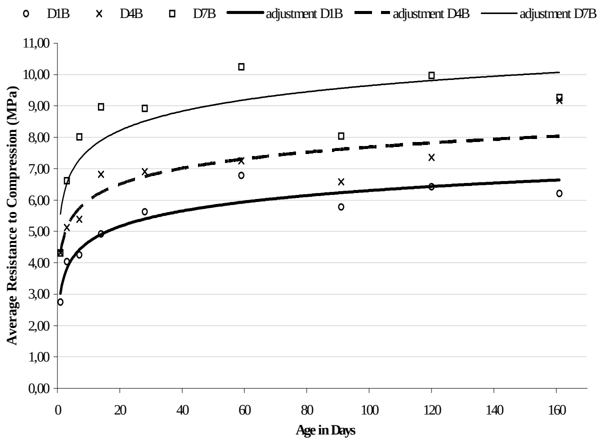

Figure 5- Compressive strength evolution

The shrinkage has been evaluated for three mix design – D1B, D4B and D7B – at 23 hours, 3, 7, 14, 28, 59,91 and 120 days. The results are presented (Figure 6).

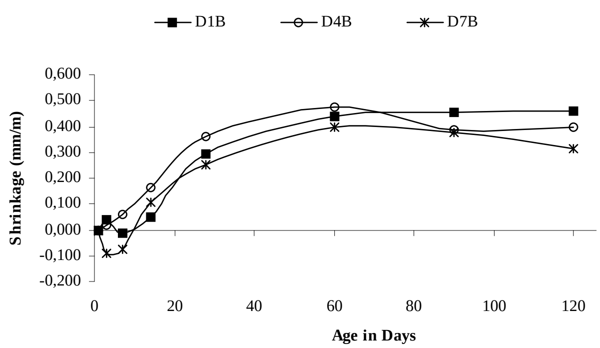

Figure 6- Shrinkage evolution

The water absorption by immersion has been determined in the mix references D1B, D4B and D7B. The water absorption by capillarity has been determined in the mix references D1B, D5B and D7B. The results are presented (Figure 7 and 8).

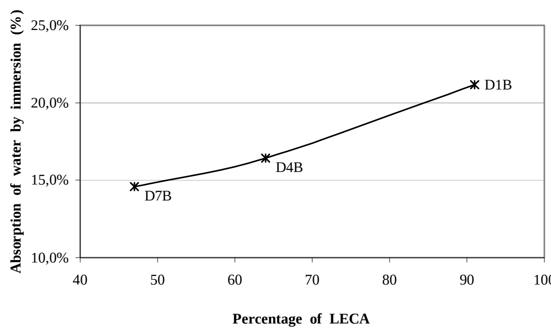

Figure 7- Water absorption by immersion of different mixes

The thermal conductivity has been determined by the hot plate method in four mix references – D2B, D3B, D4B and D7B.

The comparison between the thermal conductivity the dry bulk density and the quantity of lightweight aggregate are presented (Table 5).

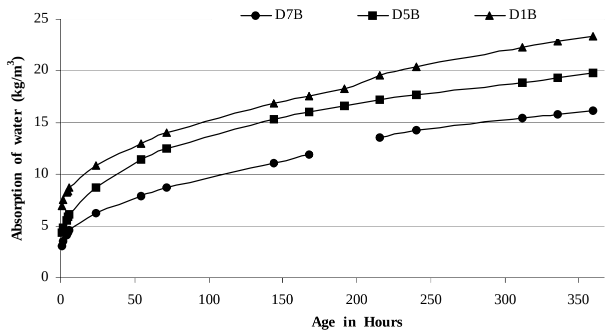

Figure 8- Water absorption by capillarity

Table 5
Thermal conductivity

Mix Reference	Dry bulk density	LECA content	Thermal conductivity
	(kg/m^3)	(%)	(W/ mºC)
D2B	919	80	0.33
D3B	950	70	0.44
D4B	1240	65	0.51
D5B	1209	60	0.48

5. CONCLUSIONS

5.1. Mix design

The main objective of the study is to evaluate the applicability of a method of design mix for special lightweight concretes, used to produce lightweight concrete blocks for masonry, and to investigate the possibility of to foresee the characteristics of concrete known the mix and the density.

The Faury method seems to be adaptable to these concretes, being the deviation between the expected and real density acceptable.

The results obtained allow to obtain a set of relations between the density, the LECA content and some properties of these concretes.

The next aspects should however be considered:

- the deviation between the expected and real density is normally negative and the volume of fines should be increased to reduce porosity and approach the real density of the expected;
- the moulding machines produces some segregation between the two sides of the mould that justifies some concentration of more light and coarse aggregates in one side; this fact is also responsible for some high deviation on mechanical properties of concretes according that those concretes are done in modern factories.

5.2. Compressive strength

The limits of the compressive strength variation of these concretes are 5,13 and 10,7 kN/mm^2 and all the observations should be intended in this purpose, related with aggregates characteristics and cement content. The experimental results show, what is obvious, that for low cement quantities, the quantity of lightweight aggregate, or the change of it for normal aggregate, has no influence on compressive strength that is always weak.

Growing the quantity of cement the compressive strength is more influenced by the reduction of lightweight aggregate (Figure 9). The evolution of the compressive strength with the time is similar to normal concretes

5.3. Shrinkage

The absolute value and the evolution of shrinkage evolution are very important for masonry materials because they affect the wall behaviour, and this fact is yet more important in lightweight concretes. For producers is important to know what time is needed to cure the blocks before they are sent to site. The results of this work shows that in normal conditions of cure at almost 28 days 70% to 75% of shrinkage have occurred and after 60 days the increment is almost null.

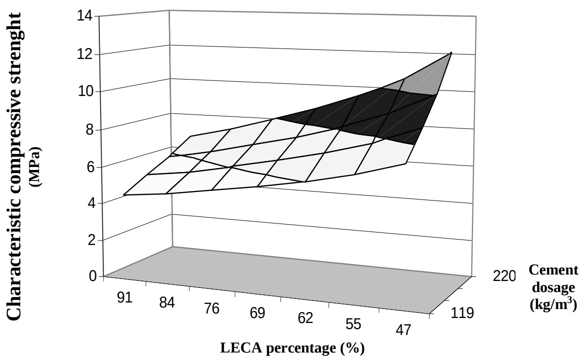

Figure 9- Compressive strength, quantity of LECA and cement quantity

5.4. Thermal conductivity

The thermal conductivity of the lightweight concrete used to produce blocks for masonry is very important because using multichamber masonry blocks, as is current in Portugal and in other south Europe countries (Figure10), is possible to assure the level of thermal insulation required for walls according Portuguese codes using a single leaf wall without any other thermal insulation material. This alternative solution to cavity walls can be a very interesting solution under economic and technologic point of view, because can be more economic, more quick to build and less subjected to workmanship quality.

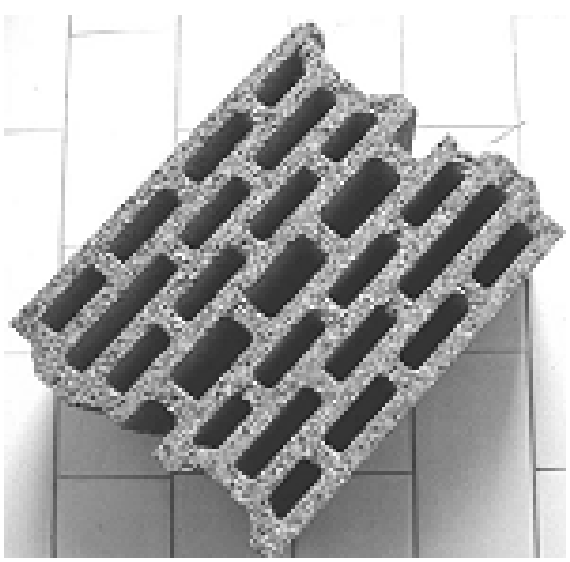

Figure 10- Example of a current masonry block for single leaf walls

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