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COMPRESSIVE STRENGTH OF LIGHTWEIGHT HOLLOW CONCRETE BLOCKS MASONRY COMPARED WITH EUROCODE 6

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ABSTRACT

This paper deals with a brief presentation of Portuguese masonry solutions, more popular materials and the tendencies associated with the development of new masonry products. After this presentation, the results of compressive strength tests carried on running bond masonry prisms, made with lightweight hollow concrete blocks, are presented. The tests are made according to CEN standards. The blocks are laid with normal or thin mortars and with two bond arrangements. It is presented that the compressive strength values calculated by the EC6 formulas are lower than the compressive strength experimental values.

KEYWORDS: MASONRY, COMPRESSIVE STRENGTH, HOLLOW CONCRETE BLOCKS, LIGHTWEIGHT CONCRETE

RESUMÉ

On présente dans cet article une description des solutions en maçonnerie utilisées au Portugal, les materiaux les plus courants et les tendences associées au dévelopment de nouveaux produits. On présente les resultats des essais de résistance à la compression de murets de paroi realisés avec blocs de béton léger d'argile expansée. Les essais sont realisés en respectant les normes CEN. Les blocs sont maçonnés avec mortier courant ou colle et avec deux appareillages. On montre que les valeurs des caractéristiques méchaniques calculées avec les formules de l'Eurocode 6 sont plus basses que celles qu'on obtient par experimentation .

MOTS-CLÉS: MAÇONNERIE, RESISTANCE À LA COMPRESSION, BLOCS EN BÉTON LÉGER

INTRODUCTION

In Portugal the way of making external walls for buildings has changed considerably. These changes haven't always a deep reflection looking for a performable solution for Portuguese conditions. As a result there are pathologies associated with some solutions.

Usually external masonry walls are of simple infilling, rendered cavity walls, made with clay bricks of high horizontal perforation and low strength; the use of thermal insulation in the cavity is frequent after the publication of the thermal comfort code in buildings by the end of the 80's. As the thermal requirements are not very severe - the U minimum value for external walls in the coldest region is 0.95 W/m^2.°C - the use of thick single leaf walls without complementary thermal insulation is increasing. This solution requires masonry units with improved thermal behaviour.

One of the masonry units used in this kind of walls are the hollow lightweight concrete blocks made with expanded clay aggregates. Those hollow blocks have a optimised shape with several levels of holes and they are laid with partially filled horizontal bed joints and dry vertical joints. Usually general purpose mortar is used, but the use of thin layer mortars is beginning. In small buildings this kind of solution can be used as resistant wall, if confined with concrete reinforcements noting that the country is on a seismic risk region, with different gradings.

In this text a review of the evolution of Portuguese solutions used in external masonry walls and in buildings structure is presented. The evolution on masonry domain to a better performance is discussed. The results of some compressive strength tests related to the thermal and mechanical optimisation of lightweight hollow concrete blocks are presented.

REVIEW OF PORTUGUESE SOLUTIONS USED IN EXTERNAL MASONRY WALLS

Portugal is a Southern European country, Mediterranean in the Centre and South, but with increasing Atlantic influences to Northwest. Except in some highlands, the weather is pleasant and the rain, associated to the Atlantic side, is more common in the North littoral. The traditional Portuguese architecture usually presents regional solutions, very adapted to climatic conditions. The use of stone in heavy and thick walls was predominant. Usually the stone walls were covered by a thick porous render, with low modulus of elasticity and made in multiple layers.

In the Atlantic seaboard, more exposed to the rain, it was usual to improve the watertightness of the render by the introduction of an water-proof layer, directly applied beside the support. With the same purpose of improving the watertightness, but with a more regional character, were used ceramic decorative coverings and claddings made of slate or fibre-cement profiled sheets, mainly on gables.

These solutions progressed on a quick way, not always adapted to local conditions, after the World War II. It's by the end of the 40's, and mainly on urban regions, that the use of concrete structures becomes widespread, first on the floors and progressively extended to the vertical support elements. The walls lost their resistance role and became only fulfilling elements, being the stone replaced by clay bricks. Clay bricks progressed from solid to large horizontally perforated elements.

The rain watertightness associated to the thickness and weight wall reduction, conducted in the 60's to the generalisation of cavity walls made of clay brick. In the 80's the care with thermal comfort and energy save, conducted to the vulgarised use of thermal insulation filling the cavity of cavity walls. In this process the tradition of rendering the walls with cimentitious mortars remained, but the quality of execution decreased and the regional character of architectonic solutions is lost. Table 1 shows the evolution of the structural solutions on the last 20 years.

Concerning the actual Portuguese external walls used in buildings we can say that:

- usually they are of simple fulfilling, cavity walls, made with clay bricks of high horizontal perforation and mechanically very fragile, the thickest leaf usually don't exceed 0,15 m and the use of thermal insulation in the cavity is frequent;
- cavity walls are generally made without wall ties, damp proof course, drainage and ventilation;
- single leaf wall solutions are not frequent, being usually made with lightweight aggregate and autoclaved aerated concrete units (such productions comprises thicknesses greatest than clay bricks);
- both, the cavity and single leaf walls, are usually covered with traditional renders, generally rich in hydraulic cement, whose finishing are usually made by painting, although the use of ceramic and stone covers has some expression;
- the cavity walls made with face bricks without external cover, aren't yet very popular but their application is increasing.

DEVELOPMENT OF NEW UNITS

As an answer to the improvement of masonry behaviour, and to an increase of rationality and economy on its construction, there are some evolutive tendencies respecting the more important requirements, Fig. 1, that we can see in Europe and in Portugal too, concerning three issues:

- the units;
- the wall concept;
- the laying process.

Concerning the units the tendency is to valuate more lighter and more thermal insulating materials, more perforated units, with large dimensions, but with enough mechanical resistance and units produced with incorporation of insulation materials, or insulating raw materials, preferably waste products.

Concerning the wall concept, the industrialised and simple execution solutions are preferred, because they are more adapted to the actual conditions of workmanship. Actually units that can answer to several requirements are preferred too, because they lead to more homogeneous walls.

Concerning the laying process, more economic solutions that allow the rationalisation and automatization of the process without reducing the performance are preferred.

The use of larger elements, the suppression of vertical mortar joints and the use of insulating mortars are becoming current.

Considering those reflections, the possibility of using thick single-leaf external walls with good thermal behaviour, and supposed to have a structural contribution in small buildings too, as been analysed. One of the masonry units that can be used in this kind of walls are the hollow lightweight concrete blocks made with expanded clay aggregates. We have been involved in a work which scope was to develop a improved shape of this kind of blocks, under a thermal and mechanical point of view, SOUSA (1996). These blocks have several levels of holes, some of them can be filled with thermal insulation materials, and they are laid with partially filled horizontal bed joints and dry vertical joints.

A sensitive analysis of the thermal behaviour of these walls has been made with a f. e. m. code and validated with an experimental study on a calibrated hot box. The evaluation of the mechanical behaviour of the walls is made with some walls test panels, which results are presented in the next point.

COMPRESSIVE STRENGHT TESTS

Units

The lightweight concrete blocks are made with expanded clay aggregates. Two kind of blocks were studied:

- a current block - 500 x 250 x 200 (l • w • h);
- a thermal improved block - 500 x 250 x 200 (l • w • h).

The shape and pattern of the two blocks are shown in Fig. 2 and 3. The blocks characteristics, presented in Table 2, were determined according:

- NFP 14-304, AFNOR (1993) - Dimensions and thickness;
- BS 6073-2, BSI (1981) - Volume of holes;

- EN 772-1, CEN (1993) - Compressive strength.

Mortars

In Portugal, mortars for masonry works, generally are site mixed and the most popular type is 1:4 cement: sand (by volume) mortar. In this work were used two mortars, whose characteristics are presented in Table 3:

- the site mixed referred mortar with a relation water/cement of 1.15 / 1.0;
- a pre-batched thin layer mortar.

Masonry specimens and bond

Three types of masonry specimens were used in order to determine the compressive strength and modulus of elasticity of masonry:

- a reference specimen according to pr EN 1052-1, CEN (1994), with 4 levels of blocks, Fig. 4, with an arrangement of ½ block length between consecutive layers;
- an alternative 1 specimen according to pr EN 1052-1, CEN (1994), but with a bond arrangement that guarantees the full overlap of blocks transversal webs, Fig. 5, arrangement of 1/3 block length between consecutive layers;
- an alternative specimen 2 equal to reference specimen, but with only 3 levels, arranged of ½ block length, Fig. 6. This specimen is easier to build and to test.

Test program

Three specimens were used to each situation resulting a total of 24 wallets built and crushed according to Table 4. Preparation, construction, curing of specimens, test procedure, loading and measurements were in accordance with pr EN 1052 – 1, CEN (1994).Tests were carried on specimens with an age of 28 days.

Results

The results were calculated according pr EN 1052-1, CEN (1994):

$$f_i = \frac{F_{i\,max}}{Ai} \qquad (4.1)$$

$$f = \overline{f_i} \qquad (4.2)$$

$$f_k = \min\left(f/_{1.2}, f_{i\,min}\right) \qquad (4.3)$$

$$E_i = \frac{F_{i\ max}}{\varepsilon_i\ 3\ A_i} \qquad (4.4)$$

$$E = \overline{E_i} \qquad (4.5)$$

A synthesis of the results is presented in Table 5.

If we compute the characteristic compressive strength and the modulus of elasticity of masonry using the formulas of the EC 6, CEN (1994) :

– $f_k = k\ .\ f_b^{0.65}\ .\ f_m^{0.25}$ (4.6)

– $E = 1\ 000\ f_k$ (4.7)

with:

$k = 0.55$ for 2a masonry group and general purpose mortar;
$k = 0.60$ for 2a masonry group and thin layer mortar;
$f_m \leq$ min (20 MPa or 2 f_b).

We arrive to the results of Table 6.

CONCLUSIONS

- Masonry structures made with lightweight hollow concrete blocks with improved thermal behaviour should be used only in small buildings, related to the very low resistance of this units;
- Mechanical resistance of this kind of units should be improved using more resistant lightweight aggregates, with the same thermal properties;
- The alternative 2 specimen, with less 1 level of blocks, allows to high test results of masonry resistance.
- For the two types of blocks analysed, although the improved block has a better compressive strength when isolated, in the wall the behaviour is almost the same. This fact should be related with the eccentricity of the two strips of mortar on horizontal joint, associated to the shell bedding;
- The expressions of Eurocode 6, CEN (1994), that establishes the characteristic compressive strength and modulus of elasticity of masonry from the compressive strength of the units and the mortar, are not well adjusted for units with low resistance as those in analysis, as shown on Fig. 7;
- The use of thin mortars (with lower resistance than a current mortar) allow to a better wall resistance.

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SYMBOLOGY

f_b' - mean value of compressive strength of a masonry unit according to EN 772-1

f_b - normalised compressive strength of a masonry unit according to EN 772-1

f_m - mean compressive strength of mortar

f - mean compressive strength on masonry

f_k - characteristic compressive strength of masonry

f_i - compressive strength of an individual specimen of masonry

$f_{i\,min}$ - smallest individual compressive strength of masonry achieved in test

E - mean modulus of elasticity of masonry

E_i - modulus of elasticity of an individual masonry specimen

ε_i - mean strain in an individual masonry specimen related to 1/3 of $F_{i\,max}$

A_i - loaded cross section of an individual specimen

$F_{i\,max}$ - maximum load reached by an individual specimen

Table 1 - Evolution of the structural solutions on residential buildings on the last 20 years (as a function of the number of residential buildings)

Year	Structural solution		
	Reinforced concrete frame	**Structural masonry**	**Others**
1975	32%	67%	1%
1980	56%	41%	3%
1985	68%	32%	0%
1990	87%	13%	0%
1992	89%	11%	0%

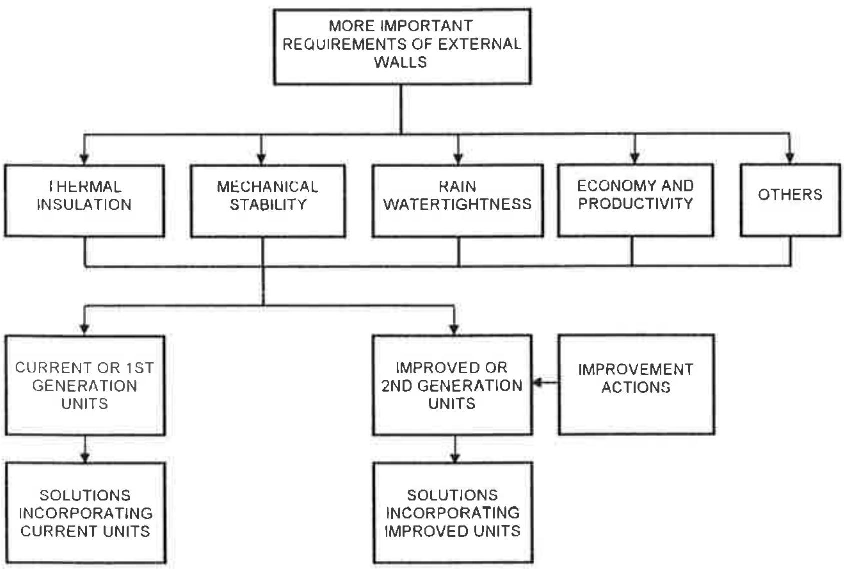


Fig. 1 - More important requirements to the design of external walls

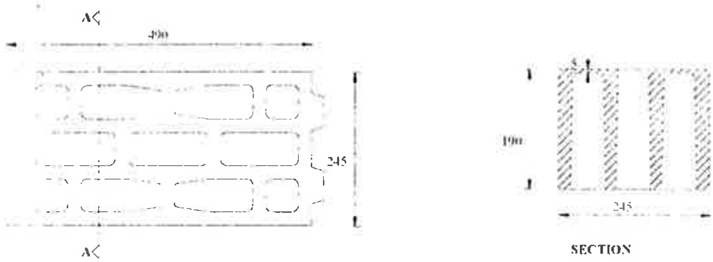


Fig. 2 - Current block - 500 x 250 x 200

Fig. 3 - Thermal improved block - 500 x 250 x 200

Table 2 - Blocks characteristics

Block	Dimensions (mm)			Thickness (mm)		Volume of holes	Compressive strength (MPa)	
	Length	*Width*	*Height*	*Face Shell*	*Web*	(%)	f_b' (1)	f_b (2)
Current 500*250*200	494	247	190	23	23	41.5	1.73	1.90
Improved 500*250*200	498	251	190	19	19	39.4	2.04	2.24

(1) - Mean value according to EN 772-1, CEN (1993)
(2) - Normalised value according to EN 772-1, CEN (1993)

Table 3 - Mortar characteristics

Mortar	Density (kg/m^3)	Compressive strength - f_m (MPa)	Flexural strength (MPa)
Site mixed	2 165	6.8	2.0
Pre-batched thin	1 200	5.0	1.9

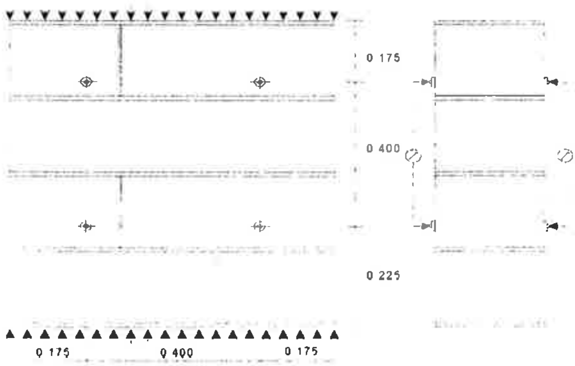


Fig. 4 - Reference specimen

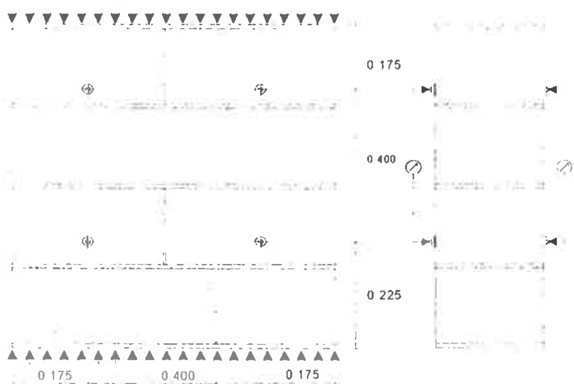


Fig. 5 - Alternative 1 specimen

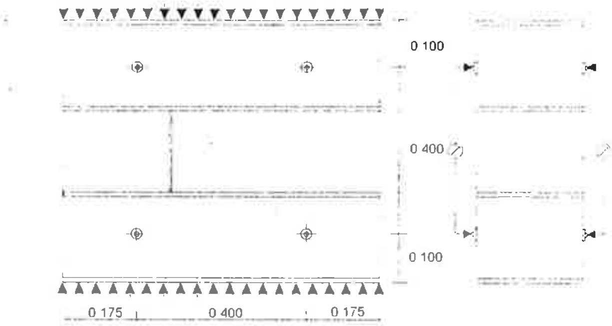


Fig. 6 - Alternative 2 specimen

Table 4 - Synthesis of tests

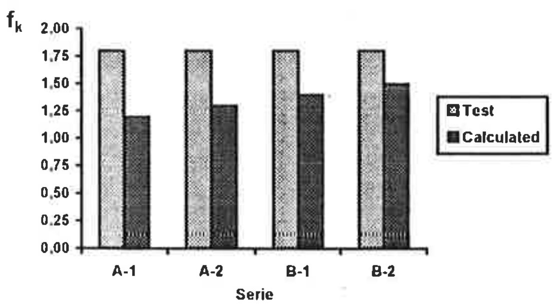
Series	Units		Mortar		Specimen		
	Current	*Improved*	*Site mixed*	*Pre-batched thin*	*Reference*	*Alt. 1*	*Alt. 2*
A - 1	+		+		+		
A - 2	+			+	+		
A - 3	+		+			+	
A - 4	+		+				+
B - 1		+	+		+		
B - 2		+		+	+		
B - 3		+	+			+	
B - 4		+	+				+

Table 5 - Synthesis of experimental results

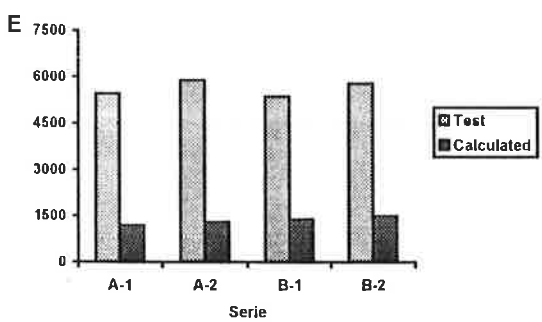
UNITS	SÉRIE	STRENGTH RESULTS (MPa)					
		Units	*Mortar*	*Masonry*			f_k/f_b
		f_b	f_m	f	f_k	E	
CURRENT	A-1	1.90	6.8	2.1	1.8	5 460	0.95
	A-2	1.90	5.0	2.2	1.8	5 900	0.95
	A-3	1.90	6.8	2.0	1.7	6 590	0.90
	A-4	1.90	6.8	2.3	1.9	5 900	1.00
IMPROVED	B-1	2.24	6.8	2.1	1.8	5 380	0.80
	B-2	2.24	5.0	2.2	1.8	5 780	0.80
	B-3	2.24	6.8	2.1	1.8	5 160	0.80
	B-4	2.24	6.8	2.3	2.0	5 950	0.90

Table 6 - Results applying EC6 formulas

UNITS	GROUP	MORTAR	STRENGTH RESULTS (MPa) *Units* f_b	*Mortar* f_m	*Masonry* f_k	*Masonry* E	f_k/f_b
Current	2a	general purpose	1.9	6.8	1.2	1 200	0.65
		thin layer	1.9	5.0	1.3	1 300	0.70
Improved	2a	general purpose	2.24	6.8	1.4	1 400	0.65
		thin layer	2.24	5.0	1.5	1 500	0.70



a) Compressive Strength



b) Modulus of elasticity

Legend:

A-1 - Current units laid with general mortar

A-2 - Current units laid with thin mortar

B-1 - Improved units laid with general mortar

B-2 - Improved units laid with thin mortar

Fig. 7 - Comparison between test results and EC6 expressions