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THIN LAYER CONCRETE BLOCKWORK IN COMPRESSION: AN EXPERIMENTAL ANALYSIS

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Abstract. The compressive strength of concrete block masonry is dependent upon the unit compressive strength, the type of unit, the mortar and the form of masonry construction (Mirza *et al.* 1995). The design codes allow masonry compressive strength to be established (or better: estimated) by calculation, from tests, or from tabulated values. In this way the current European masonry standard EN 1996: Part 1-1 (LST EN 1996-1-1) tabulates the masonry strength for concrete blocks with thin layers of mortar. In France, doubts exist on the validity of these tabulated values for the blocks made with lightweight aggregates. To provide data for an extension of the use of the tabulated values for lightweight aggregates blocks and at the same time to provide input to the development of Eurocode 6, a major research program was set up. The research program aims to evaluate the mechanical strength of the thin joints hollow concrete masonry made with dense or lightweight aggregates. Tests have been carried out on a very large type of hollow blocks. Different geometries of blocks and different types of aggregates are tested. All these tests are based on CEN standards to meet Eurocode 6 requirements. This work proves that the formula proposed by Eurocode 6 to calculate the characteristic compressive strength of hollow concrete masonry are largely safe. It was also found that the strength of masonry depends only on the block resistance and is independent of the nature of aggregate.

Keywords: thin joint, hollow concrete block, lightweight concrete units, strength, elasticity, Eurocode 6.

Introduction

The studied masonry system is based on concrete units made with dense or lightweight aggregates and bedded on thin layer mortar strip joints. This type of thin joints is developed to decrease the execution time, to improve the wall thermal characteristics and to reduce the environmental impact (Merlet 1998; Dran 1998; Sauvage, Poudevigne 2006; CERIB 2014).

According to EN 1996-1-1, characteristic compressive strength f_k of concrete masonry made with thin layer mortar, in bed joints of thickness 0.5 mm to 3 mm, may be obtained from either:

- results of tests in accordance with EN 1052-1;
- equation: $f_k = K f_b^{0,85}$;

where the constant K is obtained according to Table 3.3 of the EN 1996-1-1: K = 0.50 for thin joint concrete masonry with hollow units (units of group 3 according to Eurocode 6 (EC6) classification) without distinction between dense or lightweight aggregates;

Miriza *et al.* 1995 conducted a major research program to test the compressive strength of wallettes constructed with hollow concrete units, with collar joints and different typing arrangements. Masonry units were made using dense or lightweight aggregates and their thicknesses were 90 mm and 100 mm. Experimental results from Wallette tests were compared with the predictions of characteristic strengths made on the basis of unit strength according to Eurocode 6.

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It can be seen that the test strengths were on average, higher than the equivalent calculated characteristic strengths by 47%.

A. T. Vermeltfoort (2005) studied the mechanical behaviour under compression for masonry solid clay bricks. Comparisons were also carried out between the experimental results and the Eurocode 6 estimations. In 87 % of the 170 test results, the estimated values were indeed conservative with the Eurocode 6 provisions.

Teboul 2008 studied the compression behavior of hollow clay brick masonry with vertical holes (units of group 3 according to EC6 classification). The 30 cm thick masonry has very thin internal partitions that did not promote the efficient transfer of forces between the rows of bricks. The compression tests on wallettes showed that K-values for 20 cm clay units and 30 cm clay units were respectively 0.62 and 0.42 instead of 0.50 recommended by EC6.

H. Sousa and R. Sousa (2010) studied two masonry systems based on large lightweight concrete units and large clay units developed recently in Portugal (units of group 2 according to EC6 classification). The width of the clay and lightweight concrete units were 30 and 35 cm respectively. The units were bedded on 2 strips of thick joints mortar. They proved that EC6 overestimates the masonry strength by 11 and 54% for the lightweight concrete and clay systems respectively.

The basic assumption for establishing masonry compressive strength according to codes is that results should never overestimate the actual strength, i.e. the measured strength should be larger than the calculated strength. These previous results show that we must be vigilant on the application of tabulated values of Eurocode 6 for innovative masonry systems. It is recommended to verify experimentally the mechanical performance for new types of masonry.

In this study, characteristic compression strength of thin joint hollow concrete masonry [representative of the actual production of the French industry], made of dense and lightweight aggregates, will be determined with corresponding properties of units and mortars. The objective of this study is to verify the relevance of the formula proposed by Eurocode 6 for the two families of aggregates.

1. Presentation of the studied masonry units

The majority of the tested masonry elements have a thickness of 20 cm which represent the minimum thickness of facade walls set by the French standard for masonry works (LST NF DTU 20.1) to ensure watertightness. The length is 50 cm and the height is 20 cm. All tested units belong to group 3 according to EC6 (void volume between 25 and 70%).

The internal geometry of dense aggregate units is mainly designed to obtain the expected mechanical strength and the fire resistance of the wall. There are essentially three families of hollow blocks made of dense aggregates: the 6 holes, 8 holes and the 9 holes blocks (Fig. 1).

Lightweight aggregate units contain long, narrow and staggered cells (Fig. 2). This internal geometry as well as the density of the material, contribute to the improvement of the wall thermal resistance.

The tests involve samples consisting of block / mortar couples. The main variables are:

- the geological nature of the aggregate: dense aggregates (different types from different regions in France), pumice, expanded shale and expanded clay;
- the internal structure of the masonry unit;
- the compressive strength of the masonry unit.

In all, 31 different types of blocks were tested.

Fig. 1. Principal geometries of hollow concrete blocks made of dense aggregates

Fig. 2. Typical shape of masonry units made of lightweight aggregates

2. Building of the wallettes

Wallettes were made according to the European standard for the compressive strength of masonry (LST EN 1052-1). The wallettes were 5 blocks high and 2 blocks wide and were constructed on a base made of UPN filled with concrete to provide a basis for the assembly and then transported from the place of manufacture to the test bench.

One hundred and fifty five (1 × 1) m wallettes were built. Whole and half blocks were used. The concrete blocks were bedded with thin layer of mortar M10 with a thickness varying from 1 to 2 mm.

Horizontal joints were made using a tool adapted to the internal geometry of the block (Fig. 3). Vertical joints were not filled.

After constructing the wallettes, they were covered with polyethylene for three days to stop early drying out, and then stored in laboratory conditions at a temperature of 20 °C ± 5 °C and a relative humidity of 45 % ± 5 %.

3. Experimental evaluation of masonry mechanical characteristics

3.1. Tests on masonry elements

An experimental characterization of masonry units and mortar properties were made according to European Standards.

Hollow masonry specimens may be fully capped or capped only on their longitudinal partitions. It is important that the capping configuration be the same as the bedding in the masonry. The influence of capping on the results of hollow masonry tests has been studied by many authors (Roberts 1973; Self 1975; Hegemeier *et al.* 1978; Drysdale, Wong 1985; Maurenbrecher 1986).

The compressive strength of masonry units is obtained from compression tests according to EN 772-1 for masonry units to be strip bedded. Blocks were capped in order to reproduce the same contact area as in real situation (Fig. 4).

The compressive strength of the used mortars was determined according to the EN 1015-11. Their resistance varies between 14 and 20 MPa.

3.2. Tests on masonry wallettes

3.2.1. Test procedure

The scope of the masonry tests on wallettes is to determine characteristic compressive strength (f_k) according to European standard test method defined in EN 1052-1.

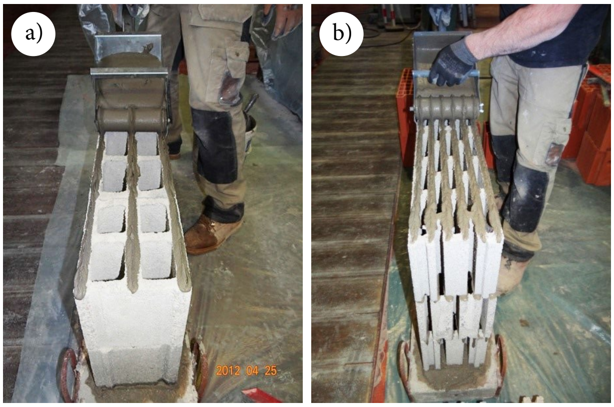

Fig. 3. Realization of the mortar bedding with the specific tool: (a) dense aggregate units, (b) lightweight aggregate units

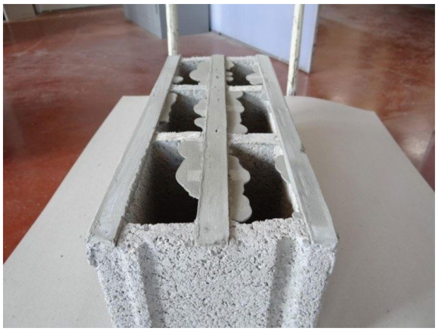

Fig. 4. Capping of masonry elements to be strip bedded

The wallettes are tested 28 days after their construction. A metallic beam is installed at the head of the wallettes in order to distribute the force applied by two synchronous jacks into a uniformly distributed load (Fig. 5). Load is applied steadily at such rate that the total test time is in the range of 15 to 30 minutes.

Fig. 5. Collar jointed wallettes ready for testing

Five wallettes were tested for each type of masonry element. The characteristic compressive strength of masonry f_k was then determined according to EN 1052-1 as the greater value between:

- min (f/1.2; f_{min});
- 5% fractile value based on a confidence interval of 95%;

where f_{min} is the lowest individual result of the 5 wallettes specimens; f is the mean strength of the 5 wallettes specimens.

3.2.2. Failure modes

Typical failure modes of wallettes made of dense aggregates units are shown in Figure 6. In most of the cases the wallettes at failure had completely disintegrated with an explosive failure. The failure was usually initiated by crushing and spalling of blocks in the middle course. The failure mode suggests that at some stage during the loading the crushing of the blocks in one leaf had resulted in an eccentric load on the other leaf. This may be due to slenderness, followed by buckling at its middle height where the cross-sectional area had reduced due to spalling and crushing.

In the case of lightweight aggregates units, the rupture occurs rather horizontally in the lower part of the wallettes (Fig. 7). The difference between these two types of ruptures can be explained by the difference in the volume of holes. In case of lightweight aggregates units, the volume of holes is close to 30% compared to close to 60% for dense aggregates units. The efforts are better distributed in the block structure in the case of lightweight units.

3.2.3. Test results and comparison with Eurocode 6

Two elongation sensors LVDT were positioned on each face of the wallette to register the elastic deformation during the compressive tests. A part of the tested wallettes was also equipped with displacement sensors to measure the deformation until collapse. These measurements show a linear elastic behaviour with low plasticity just before collapse. The limit compressive strain of the tested masonry ranges from 5×10^{-4} and 10×10^{-4} (see Fig. 8).

Eurocode 6 gives a relation between the Elasticity modulus of masonry (E) and its characteristic compressive strength: $E = K_E f_k$, with $K_E = 1000$. The involved tests indicates that Eurocode 6 estimation is very conservative for the studied masonry. K_E value should be equal to 1500 for hollow concrete masonry (Fig. 9).

The results of the characteristic compressive strength (f_k) of the tested masonry and the normalised mean compressive strength of the masonry units (f_b) are shown in Figure 10. This figure displays as well

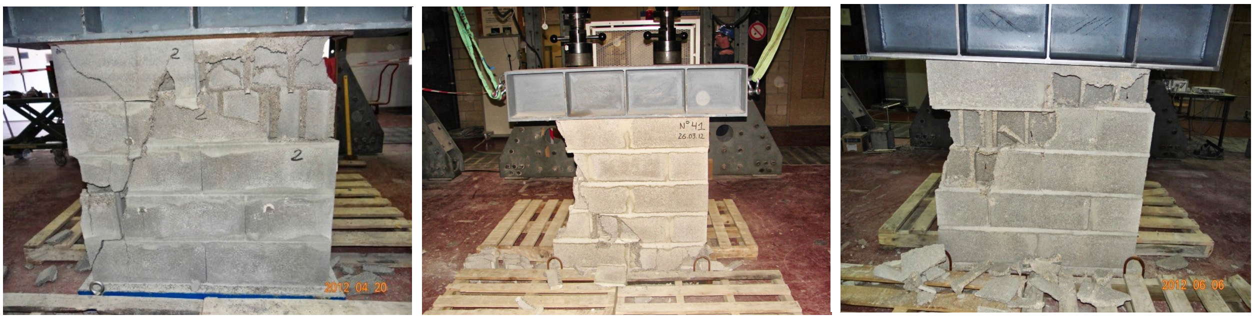

Fig. 6. Typical failure of dense aggregates masonry wallettes

Fig. 7. Typical failure of lightweight aggregates masonry wallettes

a comparison between these experimental results and those obtained by EC6.

The relative standard deviation of the 31 series of wallette tests vary between 5.9 and 20.6 %. The mean value of this relative standard deviation is equal to 12.2 %.

For all test series, the calculation of the characteristic resistance showed that the values obtained on the basis of the mean value divided by 1.2 are always greater than the value obtained with a 5% fractile and a confidence of 95 %.

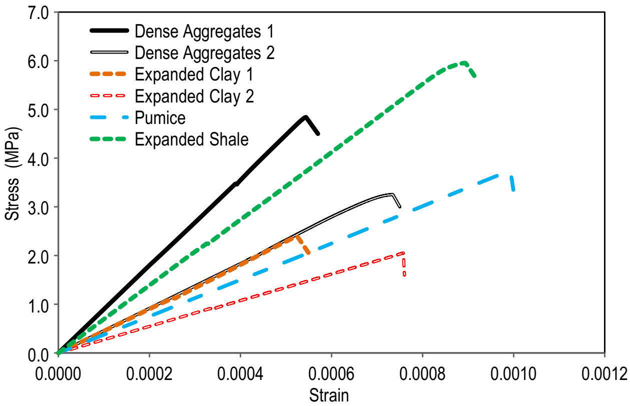

Fig. 8. Behaviour of different types of masonry systems until collapse

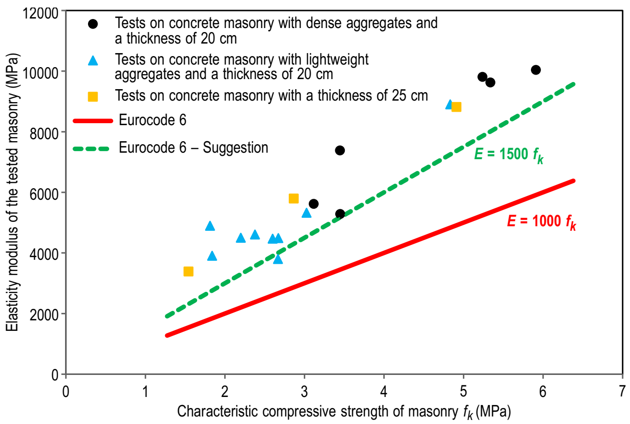

Fig. 9. Elasticity modulus for the tested masonry and comparison with Eurocode 6

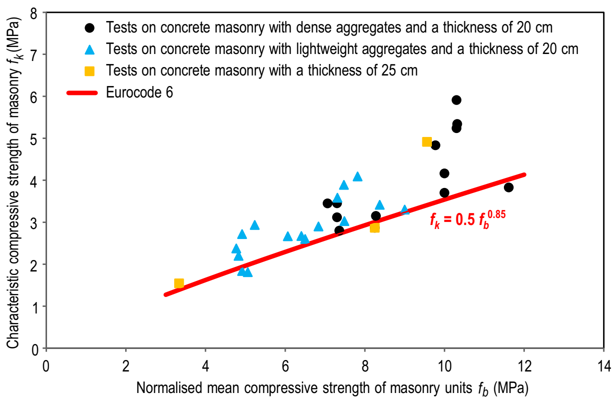

Fig. 10. Characteristic compressive strength of the tested masonry and comparison with Eurocode 6

From 27 out of 31 series of wallettes tests (i.e. 87% of all the tests), the experimental results are higher than those calculated using EC6 equation. The ratio between the experimental result and the EC6 predictions varies from 0.91 to 1.63 with an average value of 1.21.

Test results show that the characteristic compressive strength of the tested thin joint hollow concrete masonry with dense and lightweight aggregates is well estimated by the equation given by EC6 ($f_k = 0.5\, f_b^{0.85}$).

Conclusions

Current design codes permit the concrete masonry compressive strength to be determined using tabulated values. This study aims to verify the relevance of the formula proposed by Eurocode 6 for two families of aggregates: dense and lightweight. From test results several conclusions can be made:

For all test series, the calculation of the characteristic resistance showed that the values obtained on the basis of the mean values divided by 1.2 are always greater than those obtained with a 5% fractile and a confidence interval of 95%.

The calculation of the characteristic compressive strength of the thin joint hollow concrete masonry made with dense or lightweight aggregates proposed by EC6 is safe and in agreement with the experimental results. This work proves that the compressive strength of this masonry depends only on the resistance of the block and is independent of the nature of aggregate.

The compressive strain limit for hollow concrete masonry can be taken equal to $5{\times}10^{-4}$.

The elasticity modulus of the hollow concrete masonry is under-estimated by the Eurocode 6. K_E coefficient should be take equal to 1500.

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