INFLUENCE OF THE MORTAR ON THE COMPRESSIVE BEHAVIOR OF CONCRETE MASONRY PRISMS

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ABSTRACT

Finding an embedding mortar that is suitable as an infill material to be used in the vertical hollow cells of concrete block masonry is a central issue on the development of solution for reinforced masonry to be used in Portugal. An experimental study of mortars with different mixes was performed to find an equilibrium point, i.e., an intermediate mix with appropriate plasticity and sufficient workability. In this scope it is important to clarify the influence of different types of mortar, with different mechanical properties, on the compressive behaviour of concrete masonry. Thus the assessment of the suitability of the mortar as infill material is also evaluated by means of a set of uniaxial compressive tests conducted on masonry prisms with and without mortar infill. The major significance of the present work is the achievement of a proper mortar that can be used as embedding and as infill material, which involves economical advantages and can simplify considerably the constructive process of reinforced masonry.

1- INTRODUCTION

Mortar is one of the constituents of the anisotropic masonry material. It is responsible for creating a more uniform stress distribution, for corrections of irregularities of blocks and accommodation of deformations associated to thermal expansions and shrinkage. In spite of this, mortar has been often neglected in terms of structural analysis of masonry structures, it is well known that it influences the final behavior of masonry such as compressive and bond strengths, and deformability [Edgell and Haseltine (2005)]. Besides, workability of mortars plays an important role on the construction process of masonry structures. The workability may be considered one of the most important properties of mortar because it influences directly the bricklayer's work [Sabatini (1984)]. It is important to mention that the quality of the workmanship can influence considerably the mechanical properties of masonry. The workability is an assembly of several properties such as, consistency, plasticity and cohesion [Panarese et al. (1991)]. Given the fact that plasticity and cohesion are difficult to measure in situ, consistency is frequently used as the measure of the workability. In terms of building technology, the substitution of grout by general purpose mortar used for the bed joints can bring economical advantages, as it can simplify the workmanship and save time of construction. According to [Biggs (2005)], in some regions of the United States contractors commonly substitute grout by mortar in reinforced masonry construction. The use of mortar instead of grout leads to the reduction of the installation costs with low-lift applications when the masonry is to be partially grouted and reduce the number of materials. On the other hand, this means that the mortar has to present a consistency that enables the laying of the concrete units and fills appropriately the reinforced hollow cells. For this purpose, the performance of different mortars is assessed, using distinct levels of consistency, in terms of workability and mechanical properties. The distinct levels of consistency are achieved by considering different water/cement ratios.

2 – EXPERIMENTAL PROGRAM

The experimental program was divided in two studies, as follow:

Study 1 – evaluation of the fresh and hardened properties of mortar with different proportions.

Study 2 – evaluation of the behaviour of masonry prisms using some of those mortars.

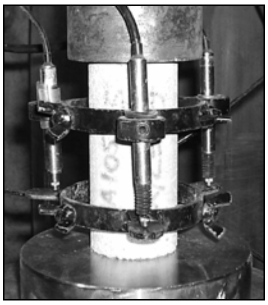
In study 1 three mixes of mortar were prepared keeping the same binder/aggregate ratio: 1:3 (Portland cement:sand), 1:0.5:4.5 (Portland cement:lime:sand) and 1:1:6. For each mix, three different water/cement ratios (w/c), see Table 1.

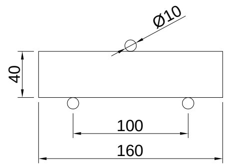
Table 1 - Mixes and corresponding water/cement ratios

Mix	Aggregates	Water/cement ratio (w/c)
1:3 (no lime)	Fine sand	0.8, 0.9 and 1.0
1:0.5:4.5	Fine sand	1.3, 1.4 and 1.5
1:1:6	Fine sand	1.7, 1.9 and 2.1

The evaluation of the fresh behaviour of mortar was carried out by means of the value of consistency obtained by means of the flow table test EN 1015-3. The elastic modulus was obtained from compressive tests carried out on cylinders with 50mm diameter and 100mm height by averaging the measurements of LVDTs attached to the specimen placed in the vertical, see Figure 1a. Compressive and flexural tests were carried out on prismatic specimens 40x40x160mm EN 1015-11, see Figure 1b.

In study 2 masonry prisms were constructed using all the mortar mixes evaluated in study 1. These tests were performed trying to better understand the behaviour of the masonry infill with mortar under compressive stresses. Masonry prisms were constructed with concrete units of three cores and with vertical joint to evaluate the influence of the infill in the block and in the vertical joint. Table 2 shows the mechanical properties of the units used to build the masonry prisms.





a) b)

Fig 1 - Details of the: a) compressive test in cylinder specimens. b) flexural tests in prismatic specimens.

Table 2 - Properties of units

	Compressive strength (MPa)	f_b (MPa)	**Elastic Modulus** (GPa)
Block	27,0 (24,69 %)	27,4	14,8 (22,13 %)
½ Block	29,6 (14,71 %)	30,0	17,3 (27,14 %)

Seven LVDTs was used to analyse vertical and horizontal displacements: four in vertical position and three in horizontal position, Figure 2. Two equal plates, one

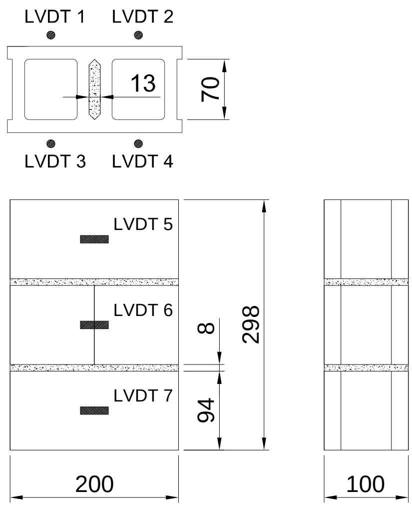


Fig 2 - Masonry prisms.

on the top and one under the specimens were used to provide similar boundary conditions. On the top a spherical roller was to correct any deviation in position of loading. The loading was applied with a displacement control equal to 0,003 mm/s.

Portland cement type CEM II/B-L 32,5N, natural hydraulic lime of class HL5 and sand were the materials used to prepare all mixes of mortars, see Table 1. Sand has a fineness modulus of 1.8 and a maximum diameter of 2.35mm. Some physical properties of materials are indicated in Table 3.

Table 3 - Mixes and corresponding water/cement ratios

Material	Density (kg/m^3)	Unit Mass (kg/m^3)
Cement	3210	1080
Lime	2720	760
Sand	2640	1450

3– RESULTS AND DISCUSSION

In this section a general overview of the results obtained in both studies is given to all the specimens.

3.1 – Study 1

In study 1 the flow table test and hardened properties (the compressive strength, f_c, the elastic modulus, *E*, and the flexural strength, f_{fl}) of mortars used in masonry prisms constructed in study 2 was evaluated, see Table 4 to Table 6.

Table 4 – Properties of mortar mix 1:3

w/c	f_c (MPa)	E (GPa)	f_{fl} (MPa)	FlowTable (mm)
0.8	7.19 (8%)	10.92 (33%)	2.57 (4%)	150
0.9	7.53 (1%)	9.02 (14%)	2.91 (13%)	180
1.0	6.89 (5%)	10.78 (8%)	2.53 (15%)	205

Compressive strength, elastic modulus and flexural strength of the mortar are properties very influenced by the water/cement ratio and the composition of the mortar, see Figure 3a to Figure 3c. As

Table 5 – Properties of mortar mix 1:½:4½

w/c	f_c (MPa)	E (GPa)	f_{fl} (MPa)	FlowTable (mm)
1.3	4.08 (10%)	6.96 (7%)	2.01 (12%)	165
1.4	3.82 (16%)	8.40 (14%)	2.02 (11%)	178
1.5	3.81 (2%)	5.94 (19%)	1.89 (13%)	200

Table 6 – Properties of mortar mix 1:1:6

w/c	f_c (MPa)	E (GPa)	f_{fl} (MPa)	FlowTable (mm)
1.7	3.49 (4%)	8.69 (16%)	1.57 (1%)	150
1.9	3.05 (15%)	6.79 (5%)	1.52 (3%)	180
2.1	2.27 (13%)	3.62 (20%)	1.12 (13%)	200

observed by Mohamad (2007), compressive strength and flexural strength showed a clear exponential and linear tendency, respectively, in its behaviour.

On the other hand, results of elastic modulus had a high dispersion and did not show a clear tendency in its behaviour.

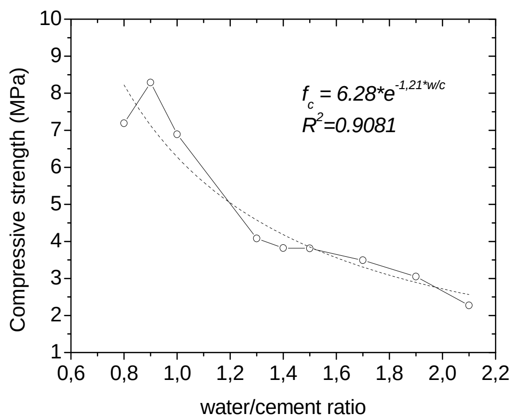


Fig 3a – Compressive strength of mortars.

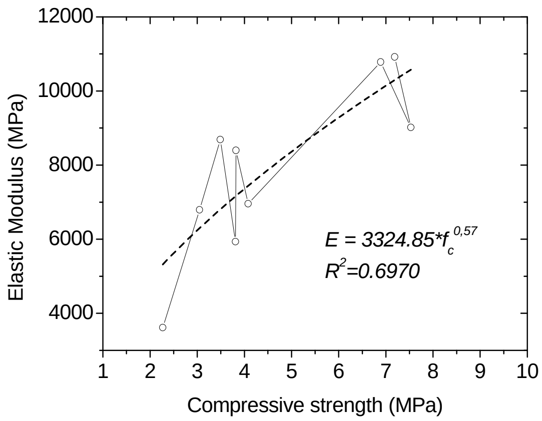


Fig 3b – Elastic modulus of mortars.

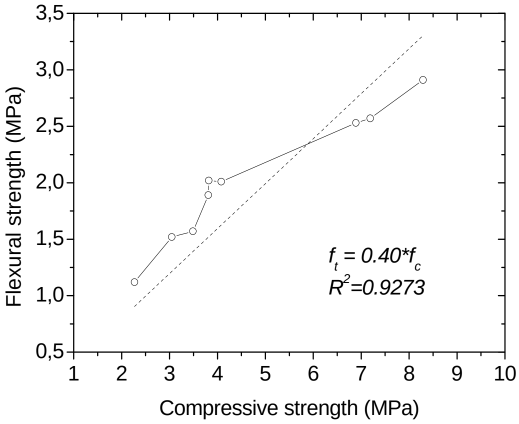


Fig 3c – Flexural strength of mortars.

As expected, it was observed that the consistence increased with the addition of water. Besides, consistence is much more sensitive to the w/c variation than the compressive strength. This behaviour is even more evident in mixes with more cement. In case of the mix with low amount of cement (1:1:6), the consistency growth in relation to w/c ratios is slower than the others mixes (1:3 and 1:0.5:4.5), see Figure 4.

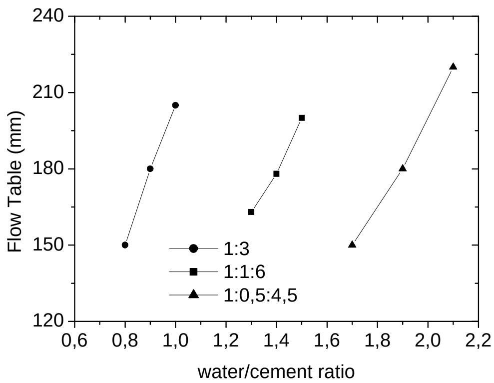


Fig 4 - Consistence – flow table.

Another factor that has high influence in workability of mortar is the use of lime. Lime in mortar allows improving some properties of workability of difficult measuring. For example: mortars with lime had a better adherence in workman tools which making easier the embedding. As concerns the goal of this study, a qualitative scale of consistency is proposed to evaluate the workability of the mortar, see Figura 5.

It was noted that the filling of vertical cores with mortars presenting flow values

SCALE OF CONSISTENCE

(Flow Table)

Dry mortar

150 mm

Mortar better to embedding

175 mm

Mortar better to fill

200 mm

Fluid mortar

Fig 5 - Scale of consistency for defining workability of mortars.

lower than 150mm was difficult to carry out. On the other hand, mortars with flow values higher than 200mm were excellent for the filling but inappropriate to the laying of the concrete units. The visual aspect, workability of the mortar and the easiness of workmanship were the main parameters leading to the definition of the appropriate mortar that simultaneously fulfill the requirements of filling and embedding.

As it can be observed, a mortar with a consistency of about 175mm is able to be used in the bed joints and in the filling of the vertical joints of the concrete masonry units.

3.1 – Study 2

In case of masonry prisms, as expected, those with infill had a higher strength than those without infill as showed in Table 7 to Table 9.

Table 7 – Results of prisms built with mortar mix 1:3

w/c	$f_{m,EN}$ (MPa)	f_m (MPa)		E_m (GPa)	
		No-infill	Infill	No-infill	Infill
0.8	8.3	14.8 (13%)	12.6 (19%)	7.9 (28%)	7.8 (17%)
0.9	8.4	11.5 (5%)	14.2 (19%)	7.1 (6%)	9.7 (15%)
1.0	8.2	12.5 (9%)	14.6 (8%)	7.1 (12%)	11.2 (8%)

Table 8 – Results of prisms built with mortar mix 1:½:4½

w/c	$f_{m,EN}$ (MPa)	f_m (MPa)		E_m (GPa)	
		No-infill	Infill	No-infill	Infill
1.3	7.0	9.8 (3%)	11.2 (14%)	6.6 (34%)	8.1 (13%)
1.4	6.8	10.7 (33%)	11.4 (12%)	7.5 (21%)	10.6 (20%)
1.5	6.8	10.6 (12%)	10.9 (1%)	5.6 (11%)	9.1 (16%)

Table 9 – Results of prisms built with mortar mix 1:1:6

w/c	$f_{m,EN}$ (MPa)	f_m (MPa)		E_m (GPa)	
		No-infill	Infill	No-infill	Infill
1.7	6.6	10.7 (14%)	11.3 (10%)	6.3 (11%)	8.2 (7%)
1.9	6.4	8.4 (34%)	11.5 (10%)	4.0 (25%)	6.1 (18%)
2.1	5.8	8.1 (26%)	10.6 (9%)	4.8 (23%)	6.1 (20%)

As observed by several authors the mortar has not a significant influence in the compressive strength of the masonry. There was a small variation in the compressive strength of the prisms since the mortar was the only variable in the specimens. The prisms with infill had a compressive strength and stiffness higher than prisms with no-infill, as expected. The values of the compressive strength were 50 % higher than those suggested in the EN1996, see Figure 6.

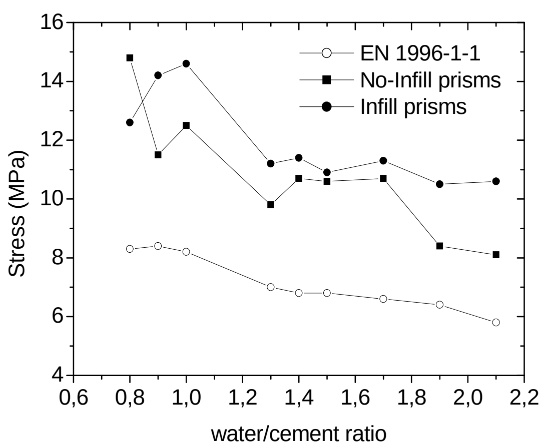


Fig 6 – Masonry Prisms – Compressive strength *vs.* w/c.

Addition of lime in mortar made the masonry more deformable vertically and horizontally. In spite of mortar to be more deformable than units, masonry prisms with infill had horizontal strains lower than prisms without infill. Moreover, masonry prisms with infill were stiffer than those without infill in all mixes, see Figure 7.

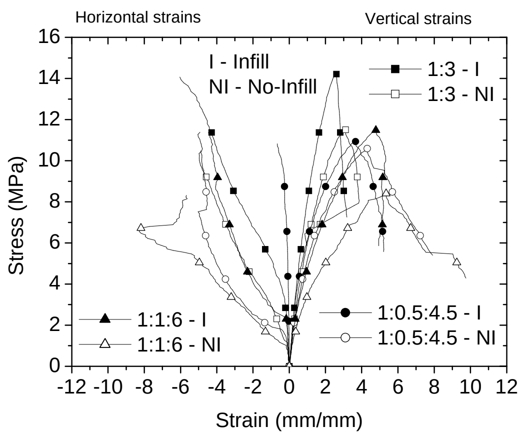
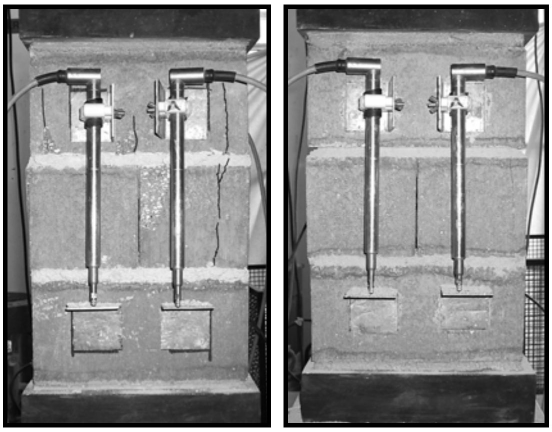


Fig 7 – Masonry Prisms - Stress vs. strain.

The cracking of the all prisms began after the ultimate load with a crack in the middle of the superior unit as a continuation of the vertical joint. In few specimens this crack also appeared in the inferior unit. After this, cracks became visible in the horizontal joints; vertical cracks appeared in extreme of the superior units and in the middle of the prisms. Internal the cracks cut the webs. The specimen reached the collapse when began the cracking in lateral face, see Figure 8a.

The masonry prisms made with the mortar 1:1:6 had a high deterioration of the horizontal joint since the mortar had a small compressive strength, see Figure 8b.

It was clearly noted two different stages of deformation in horizontal behaviour of the prisms. The first is a stage with a high stiffness, probably before the cracking. When the loading reaches approximately 20% of the strength the second stage begins. It was noted that the stiffness of this second stage is higher in prisms with infill. In spite of the material used as infill to be more deformable than the units, its expansion during the compression is negligible. In addition, the bond between the



a) b)

Fig 8 – Failure mode: a) 1:3 and b) 1:1:6.

infill and the unit made the masonry stiffer horizontally than masonry without infill.

In prisms with infill was possible to observe the crushing of the infill but without lose the bond with the unit, see Figure 9.

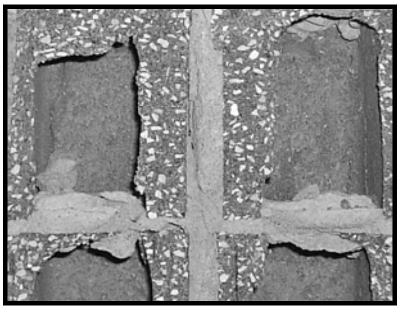


Fig 9 – Deterioration of the infill..

A curious observation was that the horizontal strains in the superior and inferior units were very different in spite of the symmetry of the specimen. The horizontal strain in inferior unit was small while in the superior unit was very similar to the horizontal strain in the vertical joint.

5 - CONCLUSIONS

The study of mortars to be used on masonry structures allowed formulating the following conclusions:

a) Mortars with the flow table equal to 175 mm are able to be used in the bed joints and in the filling of the vertical joints of the concrete masonry units;

b) Addition of lime in mortar makes the masonry more deformable;

c) Masonry prisms with infill are stiffer than masonry prisms without infill, even in horizontal deformations.

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