EFFECT OF MORTAR BEDDING AND CAPPING ON THE MECHANICAL BEHAVIOR OF CLAY BLOCK MASONRY PRISMS UNDER AXIAL COMPRESSION

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ABSTRACT

Structural masonry is a construction system whose purpose is to increase productivity, quality and efficiency. One way to increase productivity would be to only use face shell bedding, which enables faster execution. This method would also be very advantageous in reducing the quantity of mortar that is used. However, the type of mortar bedding also affects the mechanical behaviour of structural masonry. In this context, the present study's objective is to evaluate the structural performance of prisms made of clay blocks with a novel geometry and built with different types of mortar bedding. The effect of the type of capping used for the clay block prisms – full capping versus face shell capping – was also assessed. Mechanical behaviour was evaluated for two mortars with different mixture proportions and, consequently, different compressive strengths. Results show that mechanical behaviour was influenced by the type of mortar bedding: the highest compressive strength values were obtained with full mortar bedding. Capping type and mortar type were also found to have an influence, showing that it is important for structural engineers to gain knowledge of the effects described here.

KEYWORDS: clay block, mortar bedding, capping, structural masonry.

INTRODUCTION

Structural masonry is a construction system that has stirred up much interest among Brazilian construction firms due to the fact that it allows increases in quality and productivity, because it enables optimization of production processes. To boost productivity, many construction companies have opted to lay masonry units using face shell mortar bedding. This not only allows faster execution, but also reduces the quantity of mortar utilized. However, the mechanical behaviour (compressive strength and failure mode) of masonry, with face shell bedding and with the type of capping used in Brazil, is not well understood.

The majority of existing studies (be they experimental or analytical) on face shell bedding and the type of capping used in Brazilian constructions, were conducted with concrete blocks [1] [2] [3] [4] [5]. In Shrive's study on concrete blocks [1], results indicated that face shell bedded prisms "exhibited vertical cracking through the webs at lower load levels than full-bedded prisms" (p. 127). Moreover, Shrive concluded that "full capping alters the internal stress distribution considerably from that of face shell bedded masonry and will tend to reduce the strength of prisms" (p. 127) [1].

It should be emphasized that for concrete block masonry, in addition to the effect of bedding and capping type on mechanical behaviour, one must also consider the effect of tapering, which is not the case for clay block masonry.

This study's objective is therefore to examine the influence of bedding and capping type on the compressive strength and failure mode of masonry built using clay blocks with a novel geometry.

EXPERIMENTAL PROGRAM

To study the influence of bedding and capping patterns, two cement-lime based mortars and a new type of clay block were employed. The block geometry and mortars are described below.

MATERIALS

BEDDING MORTAR

Two cement-lime based mortars were used; their mixture proportions were 1:1:5 and 1:1:6 (cement: lime: sand) in volume. Mortars with said mixture proportions were selected because they are commonly employed, in southern Brazil, with blocks that have the same characteristic strength (6 MPa) as the ones used in this study.

Composed Portland Cement (CP II – Z – 32) (6-14% fly ash) and CH – III hydrated lime were used for the mortars. The characteristics of the cement and hydrated lime are detailed in Tables 1 and 2, respectively.

Table 1: Characteristics of the cement

Physical Characteristics	(%)	Chemical Components	(%)	Age (day)	Compressive Strength (MPa)
% water demand	28.2	SiO_2	22.50		
Specific gravity (Kg/l)	2.97	Al_2O_3	6.39	1	10.9
Bulk density (Kg/l)	1.03	Fe_2O_3	3.13	3	24.9
Blaine specific surface (m^2/kg)	3.637	CaO	54.21	7	31.2
		MgO	4.19	28	41.2
Initial setting time (minutes)	212	SO_3	3.14		
		Loss on ignition	5.19		
Final setting time (minutes)	264	Free lime	0.94		
		Insoluble residue	13.17		

Table 2: Characteristics of the hydrated lime

Chemical Components	(%)	Chemical Components	(%)
CaO	37.7	Insoluble residue	8.97
MgO	25.9	Bulk density (Kg/l)	0.67
Loss on ignition	26.55	Specific gravity (Kg/l)	2.40

The sand used for the mortar was natural. Its basic characteristics are presented in Table 3.

Table 3: Characteristics of the sand used for the mortars

Sieve / Size number ASTM/ABNT	% Retained Cumulative
4.75 mm / N° 4	0.0
2.36 mm / N° 8	0.3
1.18 mm / N° 16	6.1
0.60 mm / N° 30	24.4
0.30 mm / N° 50	60.3
0.15 mm / N° 100	89.2
Pan	100.0
Fineness modulus	1.80
Specific gravity (Kg/l)	2.60

The mortars were mixed according to the NBR 13276 Brazilian Standard [6]. The amount of materials used for the mortars is described in Table 4.

Table 4: Amount of materials used for the mortars

Mortar	Proportion in Volume	Proportion in Mass	Cement (g)	Lime (g)	Sand (g)	Water (ml)	w/c*	H (%)**
A	1:1:5	1: 0.65: 6.06	5250.0	3420.0	31815.0	6105.0	1.16	15.0
B	1:1:6	1: 0.65: 7.27	5000.0	3255.0	36365.0	10332.0	2.07	23.0

* - water/cement ratio
** - water/dry materials ratio

One day before production, off-the-shelf hydrated lime was mixed with moist sand (10%) to make cement-lime based mortar. After the mixture was produced, the plastic mortar's consistency was measured by means of the flow table consistency test (as per the ABNT – NBR 7215/1996 Brazilian Standard).

Water volume (provided in Table 4) was measured once satisfactory mortar workability (as evaluated by the experienced mason who constructed the prisms) had been achieved. Compressive strength was measured with 5x10 cm specimens after 28 days.

CLAY BLOCKS
The clay block studied was 140 x 190 x 290 mm (its geometry is detailed in Figure 1) and its nominal characteristic strength was 6 MPa. Values for other physical characteristics, which were evaluated using procedures described by the NBR 15270-3 [7] Brazilian Standard, are presented in Table 5.

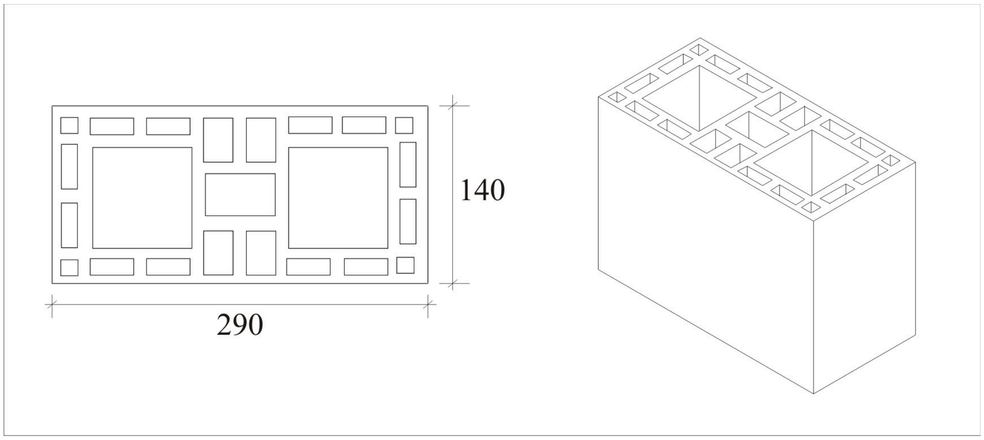

Figure 1: Clay block geometry

Table 5: Physical characteristics of the clay blocks

Results	Dimension			Area		Absorption Total (%)	Initial Absorption Ratio (IRA) (g/193,55cm^2/min)
	Width (mm)	Height (mm)	Length (mm)	Gross (cm^2)	Net (cm^2)		
Individual	138.5	190.9	292.9	404.8	181.5	17.0	53.5
	138.9	191.1	290.8	406.5	176.0	16.8	55.0
	139.3	189.9	291.4	403.0	175.7	17.1	55.1
	139.7	190.0	291.4	-	-	-	-
	138.2	191.9	290.4	-	-	-	-
	139.1	191.8	290.9	-	-	-	-
Average	139.0	190.9	291.3	404.8	177.7	17.0	54.5
C.O.V. (%)	0.4	0.5	0.3	0.4	1.8	0.7	1.8

PRISM CONSTRUCTION

For each type of mortar, four 3-block high prisms were built for different combinations of bedding techniques and capping techniques. Hence, for mortar A, 4 fully bedded/fully capped prisms, 4 face shell bedded/fully capped prisms, and 4 face shell bedded/face shell capped prisms were built. The same was done for mortar B. All prisms were capped with a cement/fine-sand paste at least 24 hours before being assembled. The prisms were constructed according to the Brazilian Standard, with a joint thickness of 10±1 mm.

Prism compressive strength and modulus of rupture were measured after 28 days.

RESULTS AND DISCUSSION

Table 6 presents the characteristics of the plastic mortar (consistency) as well as the properties of the hardened mortar (compressive strength).

Table 6: Consistency and compressive strength of mortars

Results / Mortar	Flow Table (mm)	Test Number	Compressive Strength		
			Individual (MPa)	Average (MPa)	C.O.V. %
A 1:1:5	230.5	1 2 3	3.98 3.88 4.08	3.98	2.6
B 1:1:6	248.0	1 2 3	2.25 2.02 2.10	2.12	5.5

As expected, the flow table values in Table 6 are different for each mortar since the water/cement ratio is much greater for mortar B (2.07) than it is for mortar A (1.16). The plastic mortar characteristics were somewhat predictive of the mortar's properties in the hardened state: mortar A, which had a lower water/cement ratio and a greater amount of cement than mortar B, also had greater compressive strength, as expected.

Table 7 presents compressive strength values obtained for the clay blocks.

Table 7: Compressive strength of clay blocks

Specimen	Dimension			Area (cm^2)	Load (KN)	Compressive strength		
	Width (mm)	Length (mm)	Height (mm)			Individual (MPa)	Average (MPa)	C.O.V. (%)
1	140	290	190	406.0	253.4	6.24	7.49	16.0
2	140	290	190	406.0	258.4	6.36		
3	140	290	190	406.0	258.4	6.36		
4	140	290	190	406.0	263.4	6.49		
5	140	290	190	406.0	268.4	6.61		
6	140	290	190	406.0	273.4	6.73		
7	140	290	190	406.0	278.4	6.86		
8	140	290	190	406.0	288.4	7.10		
9	140	290	190	406.0	303.4	7.47		
10	140	290	190	406.0	328.4	8.09		
11	140	290	190	406.0	348.4	8.58		
12	140	290	190	406.0	373.4	9.20		
13	140	290	190	406.0	378.4	9.32		
14	140	290	190	406.0	383.4	9.44		
Average compressive strength								

As shown in Table 7, although the average compressive strength obtained experimentally (7.49 MPa) was greater than that expected (6 MPa), an elevated coefficient of variation was observed.

Compressive strength values are presented in Table 8 for prisms built using the two mortars, two bedding patterns and two types of capping. The results are also presented in Figure 2. Prism/unit ratios (average prism compressive strength / average block compressive strength, both using gross area) are also indicated.

Table 8: Compressive strength of prisms with two types of bedding and capping

Mortar	Mortar Bedding	Capping	Compressive Strength				Prism/unit ratio**
			Individual (gross area) (MPa)	Average (MPa)	C.O.V (%)	Average for block* (MPa)	
A 1:1:5	Full	Full	6.07 5.81 6.00 6.17	6.01	2.6	7.49	0.80
A 1:1:5	Face shell	Full	4.06 3.75 4.18 4.79	4.20	10.4	7.49	0.56
A 1:1:5	Face shell	Face shell	4.58 4.86 4.69 -	4.71	3.1	7.49	0.63
B 1:1:6	Full	Full	5.48 5.29 5.12 5.04	5.23	3.7	7.49	0.70
B 1:1:6	Face shell	Full	3.76 3.24 3.59 -	3.53	14.1	7.49	0.44
B 1:1:6	Face shell	Face shell	4.47 4.34 4.38 -	4.40	8.6	7.49	0.56

* Value obtained in Table 7.
** Average prism compressive strength (using gross area) / Average block compressive strength (7.49 MPa)
- Results lost due to testing problems

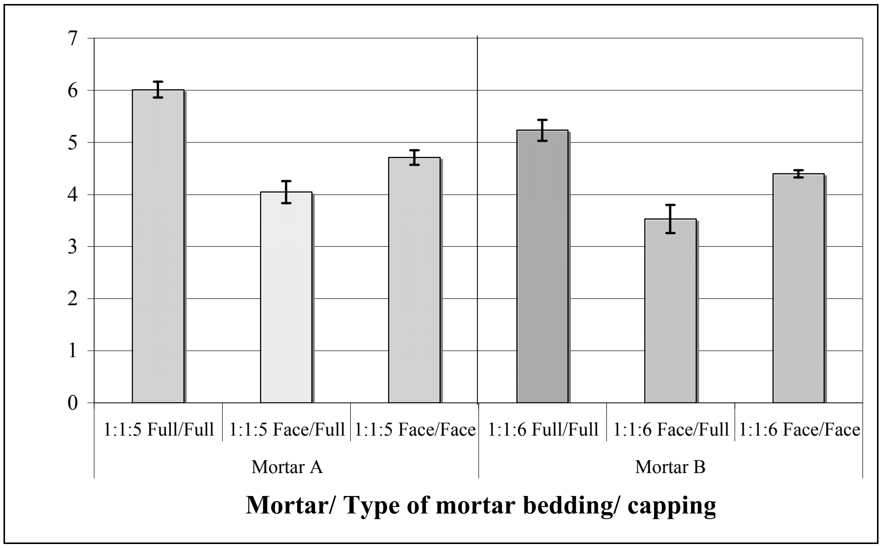

Figure 2: Prism compressive strength, according to type of mortar, mortar bedding and capping used

Table 9 presented the results of statistical analysis using 95% confidence limit and the Duncan test.

Table 9: Results of statistical test comparing average prism compressive strength values to determine the effect of mortar type, mortar bedding and capping (using 95% confidence and the Duncan Test).

Mortar Mortar Bedding Capping	**A** Full/ Full	**A** Face shell/ Full	**A** Face shell/ Face shell	**B** Full/ Full	**B** Face shell/ Full	**B** Face shell/ Face shell
A Full/ Full		-	-	-	-	-
A Face shell/ Full	Different		-	-	-	-
A Face shell/ Face shell	Different	Similar		-	-	-
B Full/ Full	Different	Different	Similar		-	-
B Face shell/ Full	Different	Similar	Different	Different		-
B Face shell/ Face shell	Different	Similar	Similar	Different	Different	

As can be gleaned from Table 8 and Figure 2, mortar type had an influence on the compressive strength of prisms with full bedding and full capping. Prisms built with mortar A had greater compressive strength than prisms constructed with mortar B (the difference is significant with 95% confidence using the Duncan Test – see Table 9). However, when the effect of mortar type was evaluated for prisms built using different bedding-technique/capping-technique combinations (for example, 'Mortar A - Face shell/Full' vs. 'Mortar B - Face shell/Full', in Table 9), it was found that average compressive strength values do not differ significantly. That is, mortar type did not influence the compressive strength of face shell bedded, full capped prisms (Face shell/Full), nor did it influence the compressive strength of the face shell bedded, face shell capped ones (Face shell/Face shell).

With respect to the effect of mortar bedding patterns (full vs. face shell), the full bedded prisms exhibited greater compressive strength than the face shell bedded ones, regardless of the mortar (A or B) and of the capping pattern used for the latter (the difference is significant with 95% confidence– see Table 9). This was expected (and had already been proven in other studies [1] [2]), given that there is a difference in failure mode for face shell bedded prisms. Such prisms exhibit early failure characterized by propagation of a crack (or cracks) up the narrow face of the prism (see Figure 3). Now, if one uses the effective bedding area (instead of the gross area) when calculating the compressive strength of the face shell bedded/face shell capped prisms, the value obtained is higher and even exceeds that obtained for full bedded, fully capped prisms (Full/Full in Table 8).

Figure 3: Failure in a face shell bedded, fully capped prism

Capping pattern did not have a significant influence on the compressive strength of prisms constructed with mortar A; however, there was an influence for those built using mortar B. It should be noted that the compressive strength of face shell bedded masonry with full capping is lesser than that of face shell bedded masonry with face shell capping (regardless of mortar type), as indicated by previous studies [1]. According to Shrive [1] this behavior is analogous to deep-beam bending. Shrive's reasoning can be applied here and broadened to account for eccentric loading and the effect of using full-capping instead of face-shell capping when testing prisms [1].

One should also bear in mind that the effect of capping type provides insight on how stress transfer might occur in actual structures. This way, if one elects to use face shell bedding in a wall, the first course of blocks and the wall/slab junction should, ideally, both also be laid with face shell bedding, thus potentially increasing the wall's compressive strength.

Given the gain in productivity and the reduction in the amount of mortar used, face shell bedding would be recommended in cases where loss of compressive strength does not jeopardize the structure. Nevertheless, mortar bedding pattern and related differences in structure failure mode should be taken into account in structural masonry projects.

CONCLUSION

The results described above enable us to conclude that mortar type, bedding pattern and capping pattern have an influence on compressive strength. In addition to significant differences in failure mode, face shell bedded prisms exhibited less compressive strength than full bedded ones. The loss in compressive strength that occurs with face shell bedding is even greater when full capping is used instead of face shell capping. For this reason, if one elects to use face shell bedding in a wall, the first course of blocks and the wall/slab junction should, ideally, both also be laid with face shell bedding, thus potentially increasing the wall's compressive strength.

REFERENCES

1. Shrive, N. B. (1982) "The failure mechanism of Face shell bedded ungrouted and unreinforced masonry" International Journal of Masonry Construction, Vol. 2, N. 3, pp. 115-128.
2. Maurenbrecher, A. H. P. (1986) "Compressive strength of hollow concrete blockwork" Proceedings of the Fourth Canadian Masonry Symposium, pp. 997-1009.
3. Page, A. W., Shrive, N. G. (1989) "A critical assessment of compressive tests for hollow block masonry" Masonry International, Vol. 2, pp. 64-70.
4. Mata, R. C. (2006) "Influence of mortar bedding on the compressive strength of concrete masonry wallettes and prims" 180p. Msc. Dissertation (Civil Engeneering Program – PPGEC) – Federal University of Santa Catarina, Florianópolis (in Portuguese).
5. Mata, R. C., La Rovere, H. L., Prudencio Jr., L. R. (2008) "Influence of mortar bedding on the mechanical behavior of hollow concrete masonry prisms under axial compressive" 14th International Brick and Block Masonry Conference, Sydney, Australia, on CD-ROM.
6. Association Brazilian of Standards (NBR). (2002) "Preparation of mortar for unit masonry and rendering with standard consistence index" NBR 13276. Rio de Janeiro.
7. Association Brazilian of Standards (NBR). (2005) "Ceramic components – Part 3: Structural and non-structural ceramic blocks – Test methods" NBR 15270-3. Rio de Janeiro.