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INFLUENCE OF GROUT ON HOLLOW CLAY MASONRY COMPRESSIVE STRENGTH

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Abstract

An experimental study is carried out on running bond clay prisms subjected to axial compression regarding the influence of grout with a view to find out efficient grout proportions in order to enhance the capacity of masonry. Different parameters that affect the compressive strength were used to the construction of the prisms. The specimens of three courses were tested at 0%, 33%, 50% and 100% of grouted cells for two different types of mortar, and three grouts. The results show that the compressive strengths of mortar and grout are not fully reflected in the strength of grouted prisms, but it is possible to achieve significant increases of strength mainly in the 100% grouted cell prisms. This fact could be very attractive to unreiforced masonry design when more resistant blocks are required only in few walls.

Keywords

Grouted clay masonry, compressive strength of masonry, running bond prisms.

1 Introduction

Structural masonry using hollow clay blocks has begun in Brazil in the mid 80s in residential constructions up to 6 storey high buildings. This fact took place simultaneously in the states of São Paulo and Rio Grande do Sul. The inherent rationalization of structural masonry buildings, along with the elimination of rendering by using blocks of good resistance to rain penetration, resulted in significant construction cost savings, very important factor during a period of great economic recession in Brazilian housing construction. In the last two decades clay structural masonry system has increased in some states of Brazil, mainly by the availability of blocks of high compressive strength produced in modular sizes. However, tests carried out in the last twenty years in Brazil (Cavalheiro and Gomes 2002) have shown that the average compressive strength of unreinforced clay walls is only 34% of the average compressive strength of the blocks, and the average compressive strength of two-

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course stack-bonded prisms is 50% of the unit strength. Therefore, it seems to be interesting the assessment of the influence of grout on the improvement of hollow clay masonry compressive strength in order to elevate the efficiency of the block on the compressive strength of unreinforced wall, even do not considering reinforcing bars. Structural clay blocks of different classes of resistance from a same manufacturer is not frequent, differently of concrete blocks; however, some structural clay block producers may provide blocks of two or three resistances, with different prices, depending on composition of clay mix, burning temperature, and even different cross sections varying coring patterns. In this case, could be very attractive to unreiforced masonry design to use, in a whole storey, block of one unique class, less resistant than that required for eventual more loaded walls, grouting a percentage of cells only of these singular walls. On the other hand, grouting has been used in unreiforced masonry, in order to enhance the resistance of wall that has not reached the expected compressive strength. Grouting may also be needed for using block of less width, when space savings is a determinant factor.

Despite the great interest, only few studies have been carried out and published in Brazil on the influence of grout on clay structural masonry. Investigations conducted by Gomes (1983), Mendes (1998) and Garcia (2000) may be mentioned. Very important works of foreign researchers have been done to study physical and mechanical behaviour of grouted prisms. It may be mentioned the contributions of Hamid and Drysdale (1979), Hamid and Chandrakeerthy (1992), Nawawy and Haddad (1990), these using, however, hollow concrete blocks, Kingley et al (1984) and of Atkinson et al (1990). The majority of these works is focused on prism analysis, due to the fact that the compressive strength of this simple masonry assemblage is the most utilized parameter by the standards for structural design of masonry structures. Specific studies are emphasized in each work, as assessment of grout shrinkage, type and time of vibration of the grout during placement and at later time, models of failure, and others. Three of these works propose formula to determine compressive strength for partially grouted masonry, in terms of unit strength, grout strength, mortar strength, ratio of net area to gross area, ratio of area of grout to area of cells, ratio of elastic modulus of the grout to elastic modulus of the block, ratio of the thickness of mortar joint to the height of the block, among other considerations. The other authors show only the axial compressive strength of the different elements and components tested.

2 Experimental programme

The masonry assemblages chosen for the evaluation of the influence of grout on compressive strength of hollow clay masonry were three-course running-bonded prisms (590mm), one and a half or two blocks long (440 or 590mm), made with hollow clay blocks with two main large-cells, being these cells filled with grout in the following proportions: 33%, 50% and 100%. Unfilled prisms were also tested. Mortar joints were 10mm. Figures 1 and 2 show 3D representation, as well as the cross-sections of the prisms used throughout the investigation. The blocks came from a same lot; the mortar was prepared with Portland cement, sand and lime, reaching two resistances (designated weak and strong); and the grout made with Portland cement, sand, lime and fine aggregate, was proportioned in order to achieve three different resistances (low, medium and high) related to the average compressive strength of the blocks. Thirteen blocks, thirty-three specimens of mortar, fifty specimens of grout and one hundred twenty running bond prisms were tested in axial compression. All materials were characterized, average net area of the blocks was determined, as well as the initial rate of absorption (IRA).

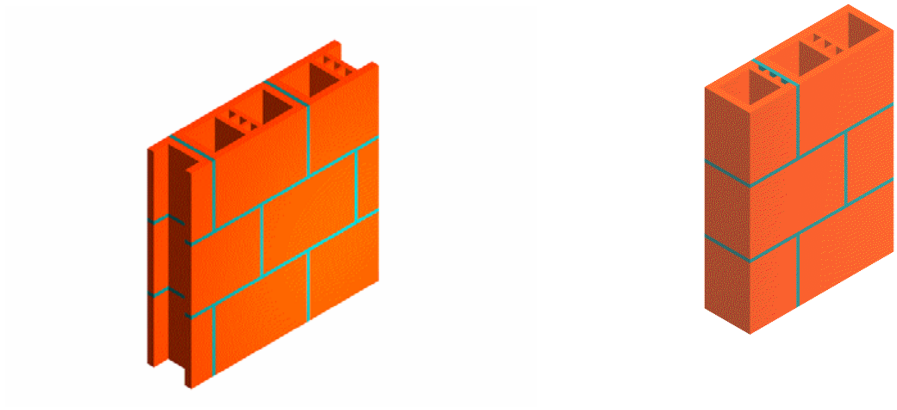

Figure 1 Types of prism used

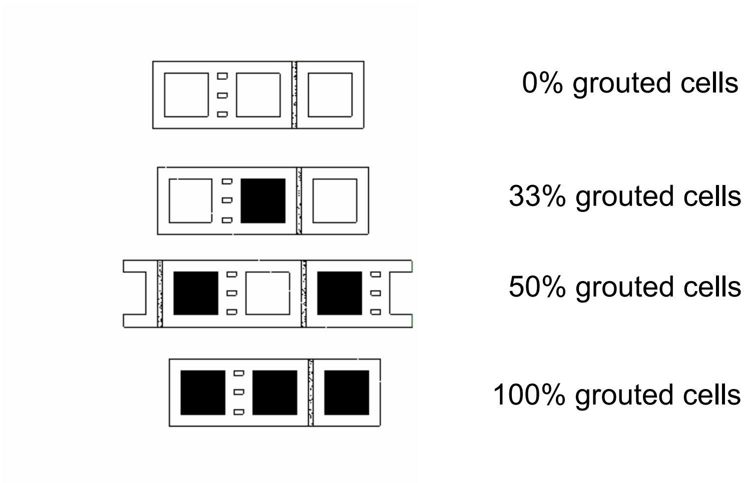

Figure 2 Cross-sections of the prisms and cells grouted

The sections of the two-model prisms were chosen in order to guarantee, in all configurations of grouting, equidistance of grouted cells to the center of the element preventing this way possible eccentricities of load during the tests.

2.1 Materials

2.1.1 Block

The units were tested according to Brazilian standards or ASTM standards in the lack of those, and all specified limits were respected. Table 1 summarizes dimensions, and the main physical and mechanical properties of the blocks.

Table 1 Physical and mechanical properties of the blocks

Mean compressive strength (Gross area)	13.08 N/mm^2 *(C.V. 11.11%)*
Characteristic compressive strength	10.98 N/mm^2
IRA (Suction)	14.38 $g/193.55cm^2/min$
Average dimensions (W, H, L)	139.7 x 190.9 x 289.9mm
Net area	18,988mm^2 (47% Gross area)

2.1.2 Mortar

Two mortar mixtures were used with Portland cement with high initial resistance (CPV), allowing early test of prisms at the age of 14 days. The mixtures, in volumetric proportions, were prepared in order to reach approximately the same compressive

strength of traditional mortar compositions using common cement (CPI), i.e: 1: 1: 6 and 1:0.25:3.75 (cement:lime:sand), consider in this work, as seen above, weak and strong, respectively. Table 2 presents the mortar mixtures along with the average compressive strength (14 days) of cylindrical specimens 100mm x 50mm diameter.

Table 2 Mortar compositions and average strengths

Mortar designation	Mortar proportions by volume			Axial compressive strength (N/mm^2)
	Cement	Hydrated lime	Medium sand	
M1	1.0000	0.6857	4.1143	6.50 *(C.V. 13.82%)*
M2	1.0000	0.1714	2.5714	18.80 *(C.V. 17.93%)*

2.1.3 Grout

The three grout mixtures were also prepared with high initial resistance cement, and proportions as well as compressive strength at 14 days of cylindrical specimens 100mm x 50mm diameter are shown in Table 3.

Table 3 Grout compositions and average strengths

Grout designation	Grout proportions by volume				Axial compressive strength (N/mm^2)
	Cement	Hydrated lime	Medium sand	Aggregate	
G1	1.0000	0.0343	2.8114	2.7429	8.93 *(C.V. 9.34%)*
G2	1.0000	0.0343	2.0983	1.8514	15.36 *(C.V. 16.00%)*
G3	1.0000	0.0686	1.3029	1.3234	26.66 *(C.V. 15.36%)*

2.2 Prisms: construction, tests, and compressive strength results

The running-bonded prisms were constructed on a smooth surface using full and half units with 10mm face shell mortar bedding. However, for 50% grouted cell prisms two different pieces obtained by cutting full unit were needed as shown in Figure 2. Excess mortar around the joint was cleared from the cells to be grouted immediately after prism construction. The grout was poured into the cells of grouted specimens in two layers, 24 hours after construction. Each layer was hand compacted using a 16mm steel rod to provide good compaction and bond to masonry joints (30 strokes per layer).

The prisms were capped and leveled properly with mortar of cement and sand (1:1, by volume) placed on the top and pressed with a leveled plaque of glass until reach a 5mm thickness capping. Gypsum-cardboard sheets 10mm thick were placed between the test specimen and the platen of the machine to distribute the load evenly. Figure 3 shows some prisms curing at the ambient air of the laboratory, and a specimen being tested.

Table 4 summarizes the mean compressive strengths of the prisms at 14 days, considering the different percentiles of grouted cells, and types of mortar and grout. Three replicates for each situation were tested. The observed modes of failure and cracking are briefly described and some representative pictures are showed in Table 5.

Figure 3 Prisms: curing and loaded in axial compression

Tabela 4 General overview of prism strength results

Mean compressive strength fp (N/mm^2) – Gross area									
Grouting percentile		0%		33%		50%		100%	
Mortar fm,14 (N/mm^2)		M1 6.50	M2 18.80	M1 6.50	M2 18.80	M1 6.50	M2 18.80	M1 6.50	M2 18.80
Grout	G1 fg,14=8.93 N/mm^2	7.35 *(9.19)*	7.66 *(12.94)*	8.07 *(8.49)*	8.65 *(9.00)*	8.04 *(16.44)*	9.34 *(6.87)*	11.58 *(5.14)*	13.30 *(5.81)*
Grout	G2 fg,14=15.36 N/mm^2	7.35 *(9.19)*	7.66 *(12.94)*	8.85 *(11.87)*	8.48 *(6.34)*	8.81 *(9.35)*	9.47 *(7.25)*	12.61 *(5.38)*	13.74 *(4.74)*
Grout	G3 fg,14=26.66 N/mm^2	7.35 *(9.19)*	7.66 *(12.94)*	8.67 *(8.43)*	8.93 *(10.16)*	8.33 *(16.41)*	10.06 *(12.76)*	13.59 *(9.23)*	15.25 *(8.19)*

Notes:
- Coefficient of variation (%) for each data set shown between brackets.
- fm,14: Compressive strentgh of mortar at 14 days.
- fg,14: Compressive strentgh of grout at 14 days.

Table 5 Modes of failure and cracking

Cells	Description	Photos
0% grouted	- Vertical tensile cracks on longitudinal faces coincident with aligned vertical joints. - Evolution of these cracks up to failure. - For mortar M2 (strong) it was observed an explosive rupture (photo on the right).	 
33% grouted	- Vertical tensile cracks on transversal faces (webs) of ungrouted cells with detachment of longitudinal faces. - For grout G1 (low strength) it was observed an explosive rupture.	 
50% grouted	- Vertical tensile cracks on transversal faces (webs) of ungrouted cells with detachment of longitudinal faces.	 
100% grouted	- Vertical tensile cracks on longitudinal faces coincident with aligned vertical joints. - Evolution of these cracks up to failure. - It was observed grout failure in some specimens.	 

3 Discussion of test results

On the basis of the prism test results and craking observed the following considerations can be made:

a) The influence of mortar strength in the prism compressive strength, independently of grout strength, was relatively small. The increase in strength of the prisms 50% and 100% grouted reached the maximum of 21% for mortar of weak strength (M1) to strong strength (M2), being lesser this percentile for unfilled and 33% grouted prisms. It is important to take into account that the mortar M2 is about three times more resistant than mortar M1.

b) The influence of grout strength in the prism compressive strength, independently of mortar strength, was also relatively small. The increase in strength of the prisms 100% grouted was about 16% for grout of low strength (G1) to high strength (G3), and less than 6% for the other situations of grouting. Grout G3 is about three times more resistant than grout G1.

c) Table 6, below, presents compressive strength ratios for prisms in the different situations studied in this work, enabling better visualization of grouting influence. It is easy to see in this table that the presence of grout into all the cells significantly increased the compressive strength of the prisms compared to the compressive strength of ungrouted prisms, ranging these augmentations from 58 up to 99 percent, according to mortar and grout strength increases. On the other hand, the increases of strength for partially grouted prisms are less significative, varying from 9 to 31 percent.

Table 6 Prisms: Compressive strength ratios

Compressive strength ratios for prisms: grouted/ungrouted						
Grout	Mortar M1			Mortar M2		
	fp33/fp0	fp50/fp0	fp100/fp0	fp33/fp0	fp50/fp0	fp100/fp0
G1	1,10	1,09	1,58	1,13	1,22	1,74
G2	1,20	1,20	1,72	1,11	1,24	1,79
G3	1,18	1,13	1,85	1,17	1,31	1,99

d) Figure 4 shows clearly that prisms confectioned with mortar M1 present nearly the same compressive strength for 33 and 50% of grouted cells. This may lead to the conclusion that the ungrouted cells would be the weaker parts of the specimens under the influence of that mortar. This conclusion seems to be also confirmed by failure modes of the prisms (See Table 5).

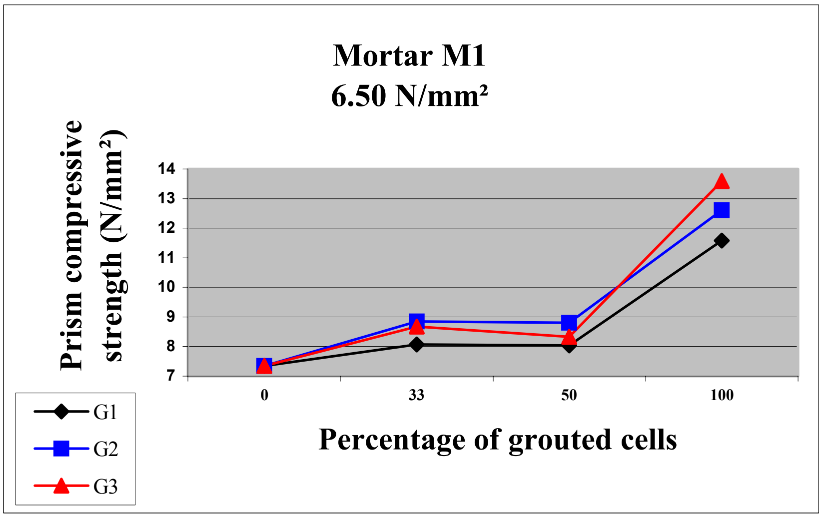

Figure 4. Prism compressive strength plots for mortar M1

e) Figure 5 shows a slight increase of the compressive strength for prisms of 33 to 50% of grouted cells, when used mortar M2. It seems that a more resistant mortar makes stiffer the non-grouted cells.

f) The best average result found for 100% grouted prisms (fp=15.25 N/mm^2) was obtained with the highest compressive strengths of mortar and grout. This value is practically two times more than that one reached in ungrouted prisms using strong mortar (M2).

g) The results in this experimental program are very close to the ones obtained from the formula suggested by Hamid and Chandrakeerthy (1992), mainly for grouts G2 and G3. The small influences of mortar and grout strength in the prism compressive strength mentioned in a) and b), as well as the ratios showed in c), were confirmed by analysis of variance.

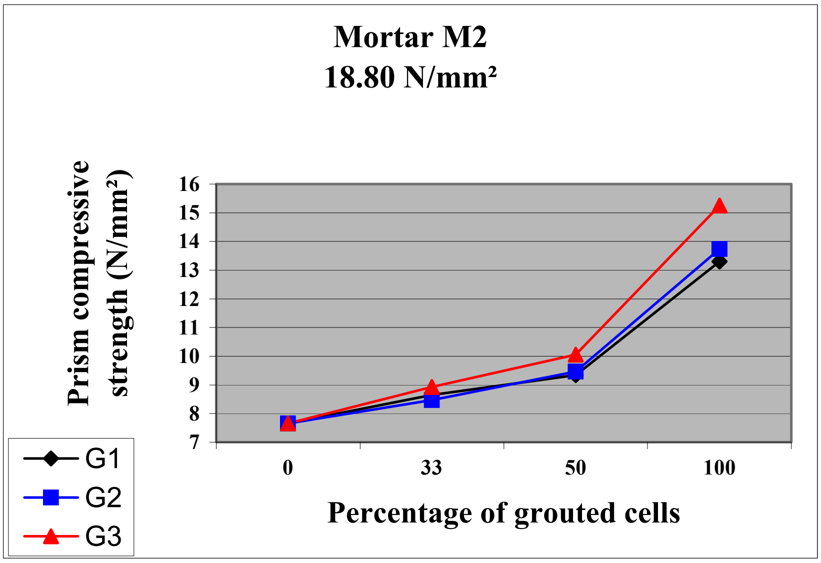

Figure 5. Prism compressive strength plots for mortar M2

4 Conclusions

The data of this research appears to support, for the studied clay blocks, the summary that:

- Grouting procedure is feasible to enhance the compressive strength of structural masonry walls, and could be very attractive to unreiforced masonry design when more resistant blocks are required only in not many walls

- Grout and mortar strengths do not significantly affect the compressive strength of prisms for a same proportion of grouted cells.

- Only for fully grouted prisms important increases in compressive strength of masonry specimens, compared to the compressive strength of ungrouted ones, are verified.

- Grouting could be very attractive to unreiforced masonry design when more resistant blocks are required only in few walls.

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