AN INVESTIGATION USING MORTAR AS INFILLING MATERIAL ON CLAY BLOCKWORK

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ABSTRACT

Grout has been used to increase the compressive strength of clay blockwork structural masonry. The new Brazilian standard for clay blockwork, ABNT NBR 15812-2 (2010), seeking greater speed of construction and flexibility for such process, allows the using of mortar to replace grout in non-reinforced masonry units. The implications of this change demand researches on the behavior of masonry units when filled with mortar. Thus, this article aims to evaluate the effectiveness of prisms infilled with mortar instead of grout. For this study, three types of mixed mortars (1: ¼ : 3; 1 : ½ : 4,5; 1 : 1 : 6) and three types of clay blocks were used. The nominal compressive strength of the blocks is of 6, 12 and 15 MPa. Preliminary results of compressive strength of the constructed prisms revealed the technical feasibility of using mortar as infilling material in substitution to grout.

KEYWORDS: clay blockwork, structural masonry, mortar, grout, prism, effectiveness

INTRODUCTION

In clay blockwork structural masonry, in certain situations of project, it is necessary to increase the strength capacity of the walls. Such structural demand can be achieved by grouting these walls, a process that consists in filling up the empty spaces inside the walls with a component named grout. Grout is a type of concrete with aggregates of small dimension and relative high flow that causes the increase of the transversal section area of the blocks, uniting them with occasional steel bars that are positioned on the inside of these blocks' empty spaces [1].

Whenever required, the grouting of the walls is done right after 24 h of the laying of the units, as it is prescribed in the ABNT NBR 15812-2 Standard [2]. However, the same standard states that grouting can be done with mortar itself right after the units are laid, provided that masonry is not reinforced.

Considering rationalization as the predominant feature of a clay blockwork structural masonry, as Parsekian and Furlan Júnior pointed out [3], the use of mortar for infilling the units right after they are laid would cause a reduction of the use and control of materials that are employed in producing grout, thus increasing the constructability of such processes, allied to inherent reduction of costs. Thereby, the main goal of this article is to investigate the effectiveness of prisms of structural hollow clay blocks when they are infilled with mortar that is employed to their laying, in substitution to grout.

The results obtained so far are part of a greater study that has been developed in the Civil Engineering Doctoral program of the first author in collaboration with the Federal University of Santa Catarina – UFSC, Brazil.

METHODS AND MATERIALS

BLOCKS

For this study we used clay blockworks classified in Brazil as of class T29, with nominal dimensions of (14x19x29) cm and nominal compressive strength stated by the clay industry as of 6 MPa, 12 MPa and 15 MPa. Each block has a different geometry as shown in Figure 1. To make it more comprehensible throughout the article, these three classes of blocks were adopted to identify them.

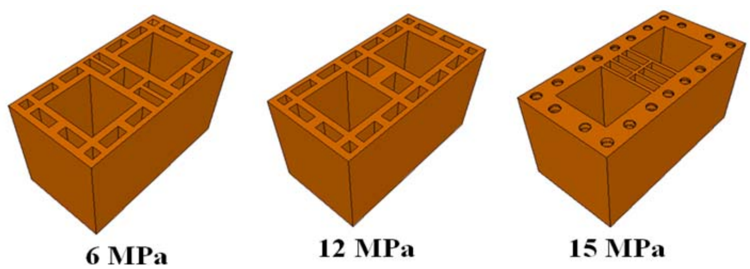

Figure 1: Geometry and respective stated nominal compressive strength of the blocks used in the research.

In order to minimize variability in the results, the sample of clay blocks is represented by a single production batch donated by Cerâmica Constrular S.A., a clay factory located in the region of the Itajaí High Valley, in the state of Santa Catarina, Brazil.

The determination of the dimensional variation, gross area, net area, initial rate of absorption (IRA) and the compressive strength of the blocks was done according to procedures established by ABNT NBR 15270-3 Standard [4]. Following the prescription of this technical standard, in order to determine the compressive strength of the blocks they had their load surfaces capped with cement paste, at least 48 h before the tests, with thickness varying between 1 mm and 3 mm. The loading speed adopted was of 0.05 ± 0.01 MPa/s using the hydraulic press SHIMADZU with maximum capacity of 2000 kN, at the Materials and Civil Construction Laboratory – LMCC of the Federal University of Santa Catarina – UFSC, Brazil.

MORTARS

The mixtures employed in producing the mortars are the ones prescribed by the British standard BS 5628: Part 1 [5], in classes (i), (ii) and (iii). Table 1 shows the class, the mixture in accordance with the British standard and the nomenclature of the mortars used in this study. However, the mixtures that were used, as prescribed by the BS 5628: Part 1 [5] are given in volume, which in this study was converted to mass in order to eliminate variations in quantities of the materials due to inaccurate volumetric measurements during the process of producing the mortars.

The consistency and the water-cement ratio (w/c) was defined in a preliminary study according to the cohesion and workability of the mortars used in the laying and the filling of the prisms. The determination of the consistency followed the procedures established by the Brazilian standard ABNT NBR 13276 [6]. The air content and the water retention capacity were also determined for each one of the mortars, respectively, in accordance with standards EN 1015-7 [7] and ABNT 13277 [8]. These features, after being obtained in tests, were maintained throughout the study and are shown in Table 1 as well.

Table 1: Nomenclature and physical properties of the mortars

Nomenclature	Class of mortar (BS 5628: Part 1-1992)	Mixture according to BS 5628 (cem: lime:sand)	Air content (%)	Water retention (%)	w/c	Consistency (mm)
A	(i)	1 : 1/4 : 3	5.8	80	0.95	± 260
B	(ii)	1 : 1/2 :4.5	6.0	75	1.45	± 275
C	(iii)	1 : 1 : 6	5.2	80	1.95	± 285

The preparation of the mortars, in accordance with the old Brazilian ABNT NBR 8798 standard [9], was performed using a vertical mortar mixer in the following order:
1) Part of the water and all of the aggregate was put into the mixer while it was running;
2) Next, the cement was put into the mixer, which was still running;
3) Following that, the hydrated lime and the rest of the water was added;
The mixing of the materials during the preparation of the mortars was held for ± 5 minutes, with the amount of water needed to give the mixture the consistency and workability as determined in previous tests.

The mechanical properties – compressive strength and flexural strength of 28 days – of the mortar was done with prismatic specimens (4x4x16) cm, in accordance with ABNT NBR 13279 Standard [10]. At least three prismatic specimens were constructed on metallic molds for each constructed and grouted prism. The tests were performed using a hydraulic press of the brand SOLOTEST at the Materials and Civil Construction Laboratory – LMCC/UFSC, with maximum capacity of 196 kN for the compressive test and of 19.6 kN for the flexural strength test.

PRISMS

Three course prisms were constructed with whole block area mortar. One opted for making the prisms with three blocks because this way the effects generated by the plate restrictions are softened on the blocks on the edges.

Three prisms were constructed for each combination of block-mortar-grout, totalizing 54 prisms with different features. The prisms were identified as grouted prism (G) or hollow prism (H), block class (6, 12 and 15) and mortar class (A, B and C). The nomenclature and the combinations used in the article are shown in Table 2.

Table 2: Nomenclature adopted for hollow and grouted prisms

Nominal Compressive Strength Of The Block	Quantity and Nomenclature of the Prisms					
	Mortar A		Mortar B		Mortar C	
	Hollow	Grouted	Hollow	Grouted	Hollow	Grouted
6 MPa	3 (H6-A)	3 (G6-A)	3 (H6-B)	3 (G6-B)	3 (H6-C)	3 (G6-C)
12 MPa	3 (H12-A)	3 (G12-A)	3 (H12-B)	3 (G12-B)	3 (H12-C)	3 (G12-C)
15 MPa	3 (H15-A)	3 (G15-A)	3 (H15-B)	3 (G15-B)	3 (H15-C)	3 (G15-C)

The prisms were constructed on a leveled granite table covered with a plastic blanket, which was anointed with mineral oil. All the blocks were moistened before the molding of the prisms. Prisms that are built with moistened blocks have a tendency to increase their compressive strength [11]. The bed joints of the prisms were done maintaining a thickness of (10 ± 3) mm. The regularization of the prisms was done with cement paste on their load surfaces in order to correct the imperfections of the prisms, hence distributing the load evenly across the active area of the section. For the hollow prisms the blocks on the edges were capped at least two days before the molding of the prisms was started. For the grouted prisms the blocks on the edges were capped after the prisms were constructed, at least 48 h before the compressive strength test, making it easier for one to prepare the prisms for the test. The grouting of the prisms was done in three layers right after they were constructed, considering that the consolidated was done with 30 hits per layer using a densifying rod according to recommendations in the ABNT NBR 8215 Standard [12]. All the prisms were ruptured through compression after 28 days of having been constructed. The loading rate used for the compressive strength tests of the prisms was of 0.05 ± 0.01 MPa/s, as recommended in ABNT NBR 15270-3 Standard [4]. The hydraulic press SHIMADZU, with maximum capacity of 2000 kN, was used for this test at the Materials and Civil Construction Laboratory – LMCC/UFSC.
Effectiveness is the ratio that exists between the strength of the prism or wall and the strength of the block. In practical terms, for this article effectiveness represents the interaction level between the components, having that the higher the effectiveness's ratio, the better this interaction will be. This ratio can be calculated as shown in Equation 1.

$$\eta = \frac{f_p}{f_b} \qquad (1)$$

Where η is the effectiveness; f_p is the average compressive strength of the prism (MPa) and f_b is the average compressive strength of the block (MPa).

RESULTS AND DISCUSSION

BLOCKS AND MORTARS

The results obtained in the physical characterization are shown in Table 3. One notices that the actual dimensions of the blocks (width, height and length) are in accordance with the ABNT NBR 15270-2 Standard [13], i.e., within the range of ± 3.0 mm for the average actual dimensions. The IRA values found for the blocks are below the value of 30 g/193.55cm² x min, which does not imply in the wetting of the blocks prior to the molding of the prisms, in accordance with ABNT NBR 15270-3 Standard [4]. However, as described in item 2.3, all the blocks were moistened prior to the molding of prisms in order to increase the performance of the prisms.

Table 3: Physical properties of the classes of blocks used in the study

Block Class	Size of the sample (N)	Dimensions (mm) and (CV - %)			Gross area (cm^2) and (CV - %)	Net area (cm^2) and (CV - %)	IRA (*) and (CV - %)
		Width	Height	Length			
6	13	137.3 (0.2)	188.8 (0.3)	288.2 (0.2)	395.8 (0.4)	158.3 (0.8)	12.6 (14.8)
12	13	141.0 (0.3)	191.3 (0.3)	290.4 (0.2)	409.5 (0.5)	204.1 (0.4)	16.1 (10.6)
15	13	140.8 (0.6)	191.1 (0.6)	288.3 (0.6)	406.1 (1.1)	221.0 (0.9)	16.6 (13.6)
CV = coefficient of variation; * AAI in g/193.55cm²/min.							

Regarding the mechanical characterization with results shown in Table 4, it appears that the characteristic compressive strength (f_{bk}) for the collected samples in each of the three classes of clay blocks results in smaller values than the nominal values stated by the provider clay industry, except for the 6 MPa class. The blocks in classes 12 and 15 show, respectively, characteristic compressive strength values that are 15% and 14% lower than the ones stated by the industry.

Table 4: Mechanical properties of the classes of blocks used in the study

Block Class	Size of the sample (N)	Compressive strength (Gross area)			Compressive strength (Net area)		
		f_b (MPa)	f_{bk} (MPa)	CV (%)	f_b (MPa)	f_{bk} (MPa)	CV (%)
6	13	11.1	9.2	11.3	27.0	22.6	13.1
12	13	14.8	10.2	15.0	30.3	23.2	11.8
15	13	16.1	12.9	14.0	32.7	24.9	11.3

The results obtained in characterizing the mortars are shown in Table 5. The values for average compressive strength are the ones expected for these mortars. It is observed that the values of average compressive strength of the three classes of mortars are lower than 70 to 100% of the strength of the blocks, as indicated by researchers Mohamad [14] and Corrêa and Ramalho [1]; except the value for the mortar class A (f_{mort}) if compared to the value for the block class 6 (f_b).

Table 5: Mechanical properties of the mortars in their solid state

Mortar Class	Sample size (N)	Average compressive strength		Average tensile strength	
		f_{mort} (MPa)	CV (%)	$F_{mort\text{-}tensile}$ (MPa)	CV (%)
A	12	12.7	9.2	3.9	13.1
B	12	6.4	7.7	2.1	9.7
C	12	3.1	9.6	1.3	7.6

PRISMS

The results obtained in the rupture of the prisms are shown in Table 6. The graphs in Figures 2 to 4 were extracted from these results, in order to facilitate the identification of behavior tendencies.

Table 6: Average compressive strength (f_p) and effectiveness factor (η) of the hollow prisms (H) and of the grouted prisms (G), laid and filled with mortars of classes A, B and C

Mortar Class	Hollow Prism (H)				Grouted Prism (G)			
	Nomenclature	Average compressive strength		Effectiveness (η)	Nomenclature	Average compressive strength		Effectiveness (η)
		f_p (MPa)	CV (%)			f_p (MPa)	CV (%)	
A	H6-A	6.6	6.8	0.60	G6-A	8.1	8.6	0.74
	H12-A	9.9	4.7	0.67	G12-A	10.9	13.2	0.74
	H15-A	10.8	9.7	0.67	G15-A	12.8	0.2	0.80
B	H6-B	5.3	15.4	0.48	G6-B	6.2	3.4	0.56
	H12-B	7.7	10.1	0.52	G12-B	8.2	5.5	0.55
	H15-B	8.0	7.1	0.50	G15-B	10.9	4.8	0.68
C	H6-C	3.9	4.9	0.35	G6-C	6.5	9.5	0.59
	H12-C	7.2	7.8	0.49	G12-C	7.8	7.9	0.53
	H15-C	9.1	12.9	0.56	G15-C	9.7	5.8	0.60

Initially, it is found that the results follow an expected behavior for both the hollow prisms and the prisms grouted with the same mortar. One notices a tendency of increase of compressive strength and of effectiveness in relation to the increase of compressive strength of the clay blocks and of the mortars used in the making of such prisms, as shown in Figures 2 to 4.

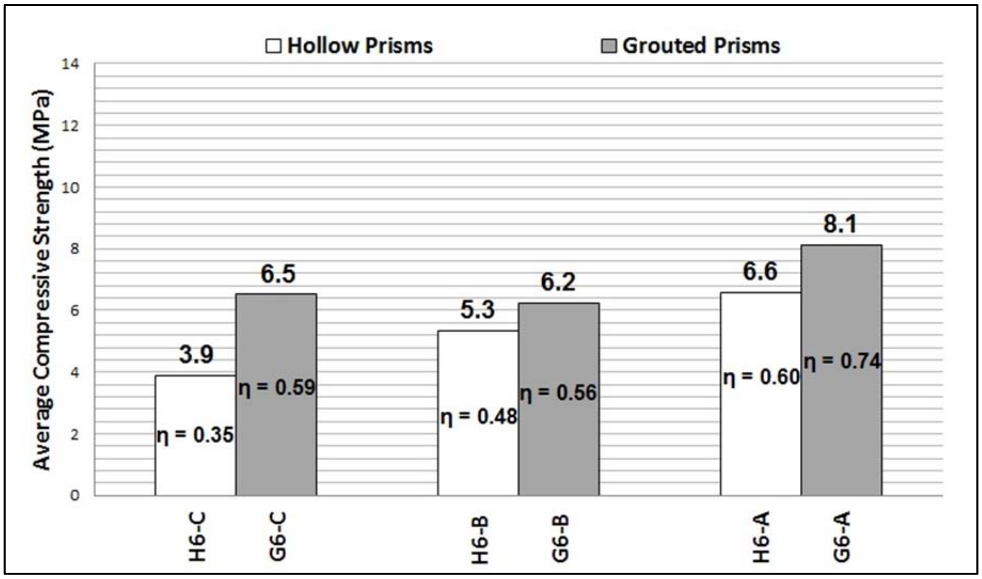

Figure 2: Average compressive strength and effectiveness (η) for prisms made with blocks of class 6 MPa, hollow and filled with mortars of classes A, B and C

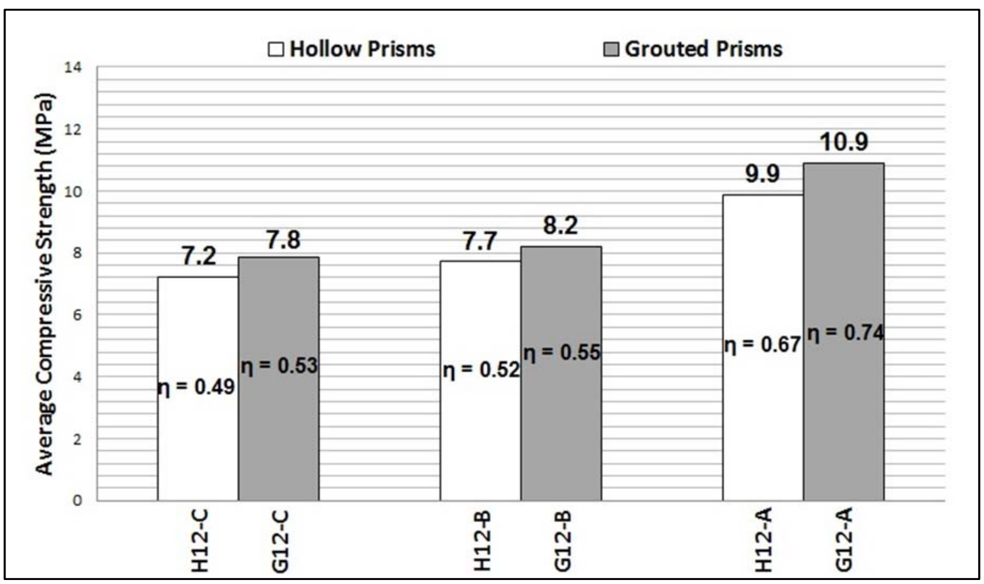

Figure 3: Average compressive strength and effectiveness (η) for prisms made with blocks of class 12 MPa, hollow and filled with mortars of classes A, B and C

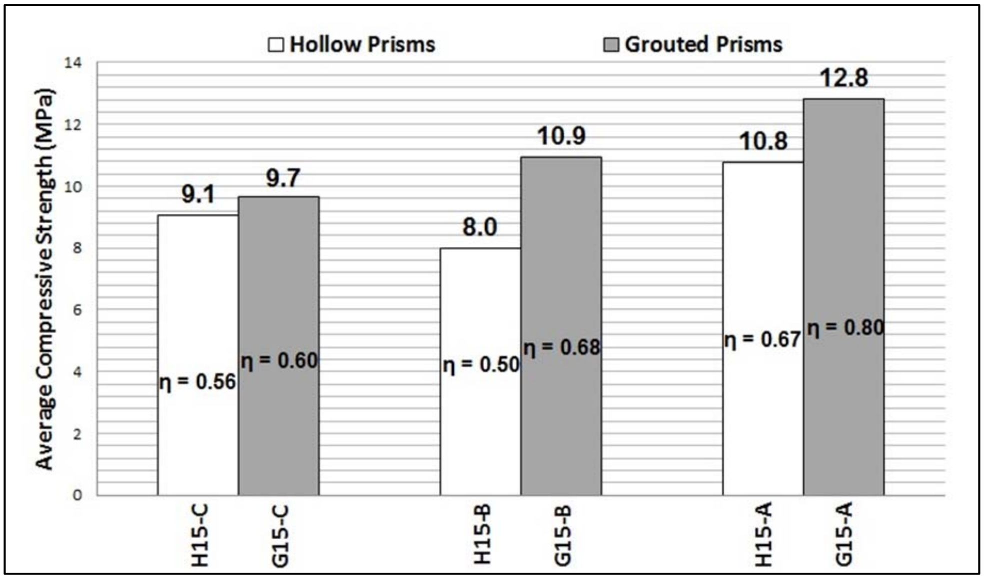

Figure 4: Average compressive strength and effectiveness (η) for prisms made with blocks of class 15 MPa, hollow and filled with mortars of classes A, B and C

When one compares the compressive strength between the hollow prisms, the prisms H15-A, H15-C and H12-A laid with mortars of classes A and C present the higher values. With the increase of compressive strength of the mortar, the prisms with same type of block had their strength increased. According to Leão [15], the hollow prisms made with blocks of same strength and with stronger mortars presented an increase in their values of compressive strength. However, such behavior was not observed when one compares the results for the prisms H15-A, H15-B and H15-C.

It is also observed that the effectiveness of the hollow prisms are in accordance with the values indicated by Corrêa and Ramalho [1] and for clay block prisms, varying between 0.3 and 0.6, except for prisms H15-A and H12-A, which presented their effectiveness factors of approximately 0.67.

In comparing the compressive strength of the hollow prisms and of the prisms grouted with same mortar, it is found that there is a tendency of increase of strength on the grouted ones, which is the expected behavior.

It is also observed that the grouting of the prisms constructed with blocks of class 6 MPa generates an increase of strength between 17.0% and 66.7%. At first, such fact demonstrates the technical feasibility of using mortar to replace the grout for prisms made with clay blocks of class 6 MPa. However, only the prisms in the series grouted with mortars of classes C and A present a significant increase, tested to a significance level of 5%.

For the prisms constructed with blocks of class 12 MPa, grouting with the three classes of mortars results in an increase of strength of the prisms between 6.5% and 10.1%. Such increase may be explained by the great difference between values of average compressive strength of the block (net area) and of the three classes of mortars. Having the behavior of regular grouts as a reference, it is indicated at least the same strength value in relation to the strength of the blocks in the net area [1] [16], so that the grout contributes effectively increasing the strength of masonry walls.

In prisms constructed with blocks of class 15 MPa, the grouting using the three classes of mortars generates an increase of strength of the prisms between 6.6% and 36.3%. The series of prisms G15-A and G15-B present the highest strength values, being the G15-A the one with highest effectiveness value (η = 0.8). The low difference between the values of compressive strength of the block (net area) and of mortar class C did not increase significantly the compressive strength of the prisms for this combination. Only the prisms grouted with mortars of classes A and B present a significant increase in their strength, tested at a significance level of 5%.

Comparing the strength values of the prisms of series constructed with blocks of classes 12 MPa and 15 MPa, the behavior expected due to the great difference observed between compressive strength of blocks and mortars did not cause a significant increase of strength of the prisms for such series when filled with mortar, which was evidenced with the prisms constructed with blocks of 12 MPa and the prisms of the G15-C series. However, as the blocks have different geometries, the interaction between the geometry of blocks of class 15 MPa and the mortar for laying and infilling them may be the main factor for the observed increase in strength of the prisms when filled. Further, according to CORRÊA and RAMALHO [1], the behavior of the prism can be negatively influenced due to the different elastic properties of the materials that compose this prism.

Although the increase in strength of the mortars generates an increase in strength of both hollow and grouted prisms, such increase is more evident in the prisms constructed with higher strength mortar, which in this experiment is the mortar of class A. This increase tendency is also observed in the effectiveness values of these prisms, i.e., with the increase in strength of the mortar, it is observed the increase of the effectiveness factor in using these combinations of prisms-mortars. Such fact has been confirmed by Leão [15], who had done researches only for the hollow prisms. According to the author, the prisms constructed with blocks of same strength and with stronger mortars present increase of compressive strength values.

In order to increase the effectiveness factor so that there occurs a significant increase in compressive strength of the prisms, it is necessary, however, a further study of the mechanical properties of the materials aiming at the correct compatibility between them, not to be limited only to their strength values but mainly to their elastic properties.

Regarding the form of rupture of the prisms, it occurred without any brittle characteristics on the hollow prisms, i.e., with prior notice through the crushing of the mortar and the formation of vertical cracks on the blocks until the collapse of the assembly, as shown in Figure 5-a. However, in the rupture of the grouted prisms, after the formation of vertical cracks on the blocks, the lateral cracking of their walls was observed, which indicates that there occurred lateral traction on the walls of the blocks, as shown in Figure 5-b. This was due to the confinement of the infilling mortar of the hollow prisms, i.e., exceeded the compressive strength of the material, the internal tension generated against the walls of the blocks causes their rupture by tensile stress [17] [18].

Figure 5: Characteristic rupture of the: (a) hollow prisms; (b) grouted prisms

CONCLUSION

The results obtained in this preliminary study demonstrate the technical feasibility of grouting the prisms with mortar aiming to increase their compressive strength. Nevertheless, such tendency is not observed for mortars that present low compressive strength in relation to the compressive strength of the blocks in their net area. Thus, a better understanding of the mechanical properties of the materials constituting the prisms is an important factor in order to assess the performance of masonry walls.

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