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Physical resistance of the flexural joint in mortar Joints and clay blocks prisms

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Abstract. In buildings, each component contributes to resisting seismic forces and an important part in this activity are the masonry walls composed of: fired clay solid brick of 120 mm width and horizontally perforated clay blocks of 100 mm and 150 mm width. The main focus of this research is to determine the flexural strength of the horizontally perforated clay block-mortar joint, using different types of mortar as established in the "Reglamento Colombiano de Construcion Sismo Resistente" for four suppliers used in the municipality of Ocaña, Colombia. A semi-automatic machine that takes into account the physics in the application of loads was designed to carry out the flexural test in mortar-block joints. The average flexural strength in mortar-block joints was determined for three types of mortar corresponding to 0.219 MPa, 0.232 MPa, and 0.291 MPa respectively, for the municipality of Ocaña, Colombia. This research established a direct relationship between the compressive strength of the mortar and the flexural strength of the 100 mm wide horizontally perforated clay mortar-block joint. A physical comparison was made in terms of the compressive strength of the prism and the flexural strength of the clay mortar-block joint with that obtained by other researchers in India and found quite similar results.

1. Introduction

In areas of intermediate and high seismic hazard, masonry failure is common, mainly due to the action of forces produced by in-plane and out-of-plane seismic events on masonry walls. The movements in the constructions presented mainly by seismic events generate loss of resistance in the masonry, compression, shear and bending due to a loss of adherence between the mortar and the horizontally perforated clay block. The loss of adhesion between the mortar and the block generates a masonry vulnerable to seismic forces, which, if the design earthquake occurs, can generate buildings with a collapse prevention performance level.

A study by Venumadhava [1] showed that the compressive strength of masonry is not significantly reduced, even when the compressive strength of mortar is reduced. The state of the art reports different failure theories for masonry composed of clay block bonded with mortar subjected to compression [2, 3]. The theories of failure rely on the deformation characteristics resulting from the multiaxial stresses of the mortar and clay block. Tests on clay block masonry


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prisms indicate that, if the compressive strength of the bond is poor, failure of the prism goes hand in hand with failure of the mortar-block bond [4, 5]. Tests on clay block, mortar-block, and masonry prism units showed that flexural strength in mortar-block joints increases with compressive strength in clay block and compressive strength in mortar-block mortar [6].

The main objective of the research was to determine the physics of mortar-clay block bond behavior for different mortar compressive strengths and different clay block manufacturers. Establishing the maximum flexural strength of the mortar-clay block joint for different compressive strength of the adhesive mortar, will allow physical and mathematical modeling of simple masonry elements, predicting cracking and loss of strength inside and outside its plane of job.

2. Materials and methods

In the construction of buildings, solid fired clay bricks are used in a handmade way and horizontally perforated clay blocks (H10) are used in an industrial way. The clay blocks used in this research were taken from the four manufacturers (Mfr.) most commonly used to make the prisms and have been designated as Mfr.1, Mfr.2, Mfr.3 and Mfr.4. Tests of compressive strength of clay block units, compressive strength of mortar for three different types of mortars.

The fineness modulus of river sand was determined, whose value is 2.89 was used to make the mortars. Forty-one prisms were built for each manufacturer, distributed as follows: 12 with type M and S mortars, while 17 prisms were built for type N mortar ($f_{cp}^{'} = 7.50$ MPa) since it is the most commonly used, for a total of 164 prisms.

The flexural test (f_g) in the joint of horizontally perforated clay block-mortar was performed at a constant rate of 8 mm/min such that the maximum applied load occurs in a time interval between 1 min and 3 min. The flexural strength at the mortar-block joint can be calculated as shown in Equation (1).

$$F_g = \frac{6\,(PL - P_l L_l)}{bd^2} - \frac{(P - P_l)}{bd}, \tag{1}$$

where F_g corresponds to the bending strength of the mortar-clay block (MPa), P represents the maximum applied load (N), P_l is the weight of the loading arm (N), L corresponds to the distance from the center of the prism to the loading point (mm), L_l represents the distance from the center of the prism to the centroid of the loading arm (mm), b is the average width of the cross section of the failure surface (mm) and d is the average thickness of the cross section of the failure surface (mm).

3. Results and discussions

Initially, the feasibility of using fine aggregates to produce the mortar was established; from a sample of 390.00 g, 387.70 g were obtained in the sum of the retained weights with an error of 0.59%, taking into account the provisions "Norma Técnica Colombiana (NTC)", NTC 174 [7]. The sieving performed on the sample indicates that the material is within the expected range of gradation, as shown in Figure 1, with a fineness module of 2.89. Other tests were performed on the fine aggregate, such as the moisture content of four samples, indicating that the average moisture content was 5.90% with a standard deviation of 0.40%, according to the established procedure in NTC 1776 [8].

As for, the average absorption percentage of the fine aggregate using three samples of 500 g each, was 7.34% with a standard deviation of 1.63% and an average bulk density of 2.13 gr/cm^3 with a standard deviation of 0.06 gr/cm^3, see standard [9]. Finally, the average density of the cement was 3.03 gr/cm^3 with a standard deviation of 0.002 gr/cm^3 [10]. Figure 2 shows the behavior of the compressive strength (MPa) of solid horizontally perforated block units vs. Mfr. marketed in Ocaña, Colombia.

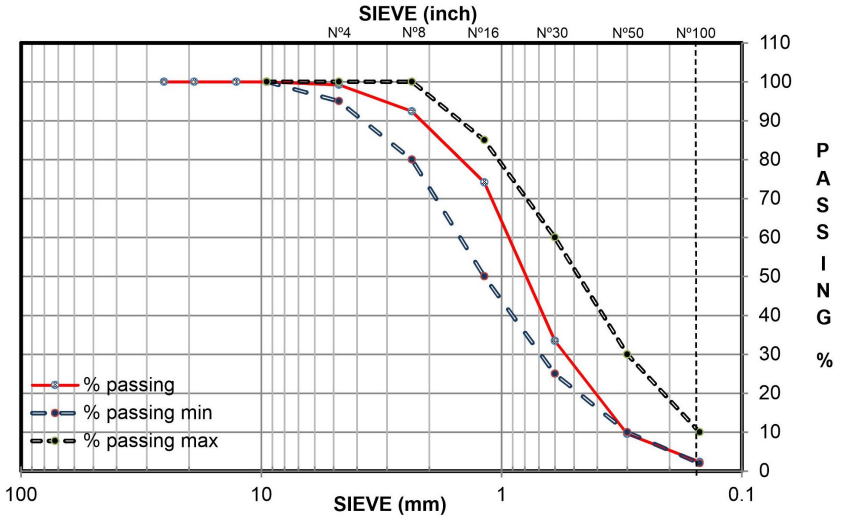


Figure 1. Granulometric curve of fine aggregates, according to [7].

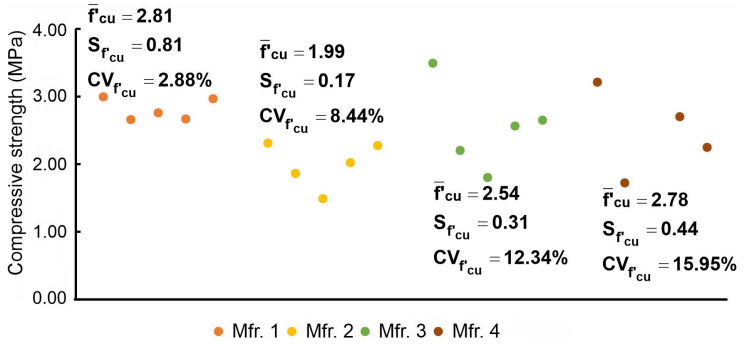


Figure 2. Compressive strength of horizontally perforated clay block units by manufacturer.

For a sample of five units, the average value of the compressive strength $\bar{f}'_{cu}$ (MPa), was obtained, as well as the statistical parameters, standard deviation $S_{f'_{cu}}$ (MPa) and the coefficient of variation $CV_{f'_{cu}}$ (%) by manufacturer. Mfr. 3 and Mfr.4 have similar results, but lower than those obtained by Mfr. 1 and Mfr. 2, possibly because they coincide in the extraction point of the mixing material. Mfr. 2 has the lowest $S_{f'_{cu}}$ of all the other manufacturers but its $\bar{f}'_{cu}$ is the lowest; however, its results are homogeneous with respect to the f'_{cu}, while Mfr. 1 has the highest $\bar{f}'_{cu}$.

The "Reglamento Colombiano de Construcción Sismo Resistente (NSR)", NSR-10 [11] establishes in section D.3.4 mortar for gluing; the types of mortar used are: M, S and N as indicated in Table 1. The expected compressive strength of the mortar is denoted as $f'_{cp_{esp.}}$ (MPa), dosage weight represents the dosage in weight of sand with respect to cement, $f'_{cp_{enc.}}$ (MPa) corresponds to the found compressive strength of the mortar and W/C is the water-cement ratio.

The dosage by weight presented in Table 1 was used in the present research. Table 2 indicates the quantity of horizontally perforated clay block prisms produced per manufacturer and per type of mortar. Table 2 shows different quantities of prisms used and constructed ( ), which depend on the time used to perform the masonry flexural bond strength test. Nineteen results

were used for Mfr. 1 that complied with the established by American Society for Testing and Materials (ASTM), ASTM-1072 [12], regarding the estimated test time, that is, between 1 min and 3 min. Of the 41 specimens produced, only 19 specimens complied with the expected time. As the strength of the mortar increases, it is more complicated to define the displacement loading rate to guarantee the time interval established by [12].

Table 1. Parameters and properties of the mortar.

Mortar type	$f'_{cp_{esp.}}$	Dosa. weight	Fluidity (%)	$f'_{cp_{enc.}}$	W/C
M	17.50	1:1	110.07	18.14	0.42
S	12.60	1:2	112.14	13.56	0.54
N	7.50	1:3.5	115.68	9.15	0.66

Table 2. Number of clay block prisms tested and manufactured

Manufacturer	Mortar type	Number	Total
1	M	4 (12)	19 (41)
	S	5 (12)	
	N	10 (17)	
2	M	3 (12)	17 (41)
	S	5 (12)	
	N	9 (17)	
3	M	6 (12)	21 (41)
	S	7 (12)	
	N	8 (17)	
4	M	3 (12)	13 (41)
	S	4 (12)	
	N	6 (17)	
Total			70 (124)

( ) total number of prisms made

The average flexural strength of mortar joints as a function of Mfr is shown in Figure 3. The average flexural strength of the manufacturers marketing horizontal drilling clay block in Ocaña, Colombia, using type M mortar is denoted by $\bar{f}_{g_M}$. The average flexural strength of the mortar-block joints for the four manufacturers is 0.291 MPa for type M mortars, 0.232 MPa for type S mortars and lastly for type N mortars is 0.219 MPa (type of mortar most used in this area). That is, for the purpose of vulnerability analysis of buildings with a structural system using masonry, it is recommended to use 0.219 MPa as the flexural strength between the mortar joint and the horizontally perforated clay block.

The F_g using type N mortar (0.219 MPa) is slightly lower than that found for solid fired clay brick using type N mortar (0.24 MPa). Similar results were found for the same brick with mortar type S, whose F_g value is 0.245 MPa while the F_g for prisms built with solid clay brick is 0.252 MPa and for prisms made with horizontally perforated clay block is 0.291 MPa. Although the contact area between the mortar and the clay block is smaller than that of the solid brick and mortar, the F_g is higher in the clay block for type M mortars, possibly due to the notched surface of the block versus the flat surface of the brick.

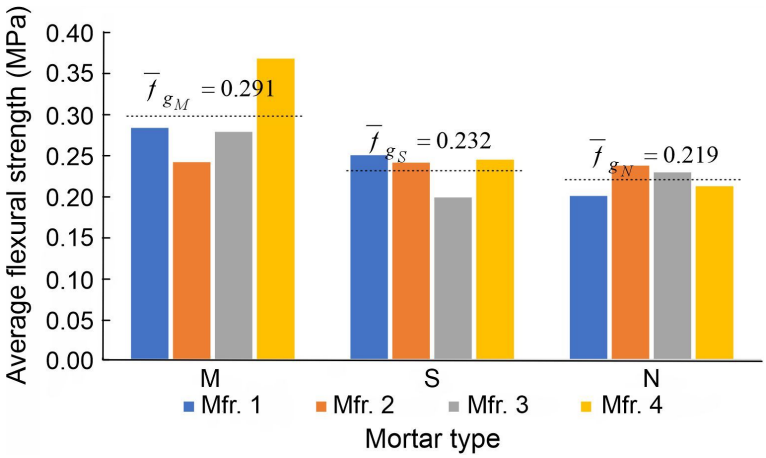


Figure 3. Average flexural strength in mortar joints with respect to mortar type and manufacturer.

Figure 4 shows the relationship between f'_{cp} and F_g per manufacturer, the average of the results and the linear regression of the average values. The first two statistical moments for the results of F_g vs. f'_{cp} type N for the four manufacturers are: 0.22 MPa and 0.014 MPa, while for type S mortar the average value and the standard deviation are: 0.23 MPa and 0.020 MPa respectively.

Finally, type M mortars have an average value of $F_g = 0.29$ MPa and standard deviation of 0.046 MPa. It was observed that there is a direct relationship between F_g and f'_{cp}, with an increase in dispersion as f'_{cp} increases, as can be seen in Figure 4. The equation relating f'_{cp} and F_g was determined with a coefficient of determination (R^2), $R^2 = 0.88$. In other words, it is possible to establish the physical behavior of the mortar-prism joint, clay block composites for design purposes, revisions and reinforcement in clay block walls.

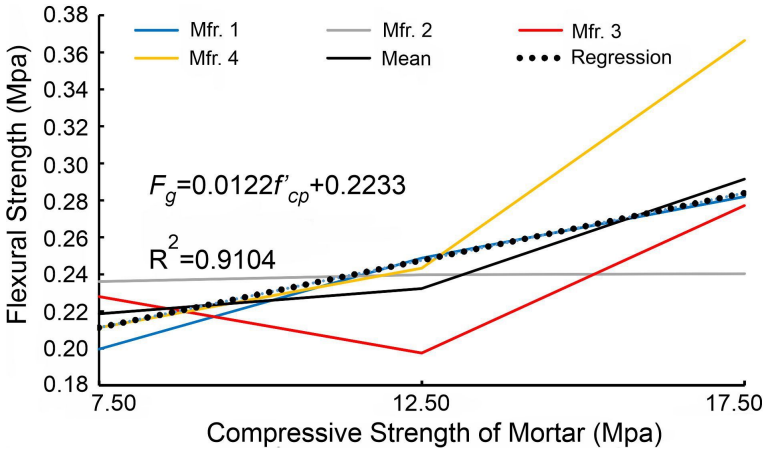


Figure 4. Flexural strength as a function of the compressive strength of the mortar.

A similar investigation was carried out by Sarangapani on solid fired clay brick prisms [13,14], with compressive strength f'_m and the types of mortar S and N, similar to those determined in this investigation for clay blocks. The two types of prisms used by Sarangapani correspond to the designations CM1 and CM2, see Table 3.

Using S type mortars with $f_{cp}^{'} = 13.810$ MPa, this research determined that $F_g = 0.232$ MPa for horizontally perforated clay blocks; whereas, the research carried out by [13] for $f_{cp}^{'} = 10.570$ MPa obtained a lower F_g than the one obtained in this research. This difference in F_g was due to the difference in contact area, surface area and compressive strength of the prism. As for a lower mortar strength (type N), the differences were notorious, possibly due to the fact that the lower prism strength decreases the adhesion between mortar-brick, possibly due to the lack of irregularities on the surface [15–17].

Table 3. Comparison of compressive and flexural strength of mortar joints in prisms.

Strength	S (MPa)	CM1 (MPa)	N (MPa)	CM2 (MPa)
$f_m^{'}$	13.810	10.570	7.240	7.320
f_g	0.232	0.205	0.219	0.088

4. Conclusions

For mortars with higher compressive strength, the greater the dispersion in the flexural strength of the clay mortar-block joint, whereas, as the compressive strength of the mortar decreases, the dispersion in the flexural strength of the mortar-block joint decreases. This allowed to establish the flexural strength in the mortar-block joint in prisms in a more evident way, and thus, for mortars type N with $f_{cp}^{'} = 7.5$ MPa the $F_g = 0.219$ MPa. This research allowed establishing a relationship between $f_{cp}^{'}$ and F_g in horizontally perforated clay block prisms, which allows establishing the flexural strength at the joint in the range of 7.50 MPa to 17.50 MPa. The physical resistance to bending of the mortar-clay block joint will allow to predict cracking in simple clay block walls and determine the level of vulnerability of any building with a system composed of horizontal perforation block walls.

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