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# Strength of the flexural joint of mortar joints and solid fired clay brick prisms

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**Abstract.** Masonry constructions built with mortar and solid fired clay bricks are subject to: high cement content, excessive water-cement ratio causing problems of mortar shrinkage during curing and differential movements between the brick and mortar caused by movements due to wind or seismic events. Earth movements generate some failures in simple masonry walls and confined masonry in solid brick joints, mainly with failure inclination angles varying from 45 degrees to 50 degrees. The objective of this research work was to estimate the flexural bond strength of the mortar joint and the solid fired clay brick and thus establish design parameters for non-structural masonry in the municipality of Ocaña, Colombia. From the fired clay brick manufacturers, 18 in total, simple random sampling was used to determine the sample size, 4 manufacturers were randomly selected. In addition, the characterization of the solid fired clay brick units was carried out with respect to their compressive strength, initial absorption rate and final absorption, as well as the mortar with respect to its compressive strength at 28 days, according to the Colombian standard for earthquake resistant constructions; for the determination of the flexural strength of the bonding mortar and solid brick units, a semi-automatic machine for flexural strength testing of masonry units, Pinzuar model PC-13, with a force measurement of 1000 N and an accuracy of 0.1 N, was designed. The flexural strength at the masonry joint was obtained for mortar type M with a value of 0.26 MPa, with a standard deviation of 0.01 MPa and a coefficient of variation of 4.72%. As for mortars type N and S, the average strength value was equal to 0.24 MPa for the two types of mortar, with standard deviation of 0.03 MPa and 0.01 MPa respectively, and coefficient of variation of 11.4% and 3.18% respectively. Given the importance of the variables, an interpretation of physical of the relationship between the properties was made: compressive strength of the solid fired clay brick and flexural strength at the masonry joint, since their average values were similar.

## 1. Introduction

In seismic hazard zones, failure of masonry elements is common due to the action of in-plane and out-of-plane seismic forces on masonry walls. In some cases, this is due to the loss of adhesion of the bonding mortar with respect to the solid brick, which generates a loss of resistance of the wall to compression, shear, and bending. This pathology causes structural elements vulnerable to seismic action that can result in human losses if the design earthquake occurs.



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The literature reports different failure theories for compressed fired clay brick masonry [1–4]. Grenley [1] carried out a study of the influence of various types of mortars on the flexural strength and compressive strength of solid clay masonry units, as well as on the tensile strength of the brick assembly. The theories are based on the deformation characteristics due to multiaxial stresses of brick and mortar. Researchers estimate that the bond between the brick and mortar remains intact at the time of mortar or brick failure. However, experiments on solid fired clay brick masonry prisms indicate that, if the bond strength is poor, prism failure is accompanied by failure of the brick-mortar bond [5, 6]. The results showed that the flexural and tensile strength of the brick-mortar bond increased with the compressive strength of the brick and the compressive strength of the mortar.

It is important to determine, for buildings constructed using solid fired clay brick masonry, the strength of the joints between the solid brick and the mortar. This resistance will establish the physical vulnerability to a seismic event of the masonry walls built in Ocaña, Colombia. The main objective of this work was to determine the physical influence of the compressive strength of the mortar in solid fired clay brick prisms.

## 2. Materials and methods

The fired clay bricks, are typically manufactured using a manual molding process and then fired in the traditional oven, for this research were taken fired clay bricks from four different manufacturers located in two municipalities in the North of Santander Department, Colombia, and have been designated as manufacturer 1 (Mfr.1), manufacturer 2 (Mfr.2), manufacturer 3 (Mfr. 3), and manufacturer 4 (Mfr.4).

The compressive strengths of the manufacturers of fired clay solid brick units Mfr.1, Mfr.2, Mfr.3 and Mfr.4 were 13.33 MPa, 12.79 MPa, 10.23 MPa, and 14.47 MPa, respectively. The highest coefficients of variation were found for the manufacturers Mfr.2 and Mfr.3 with 20.85% and 18.16% respectively. Water absorption values ranged from 15.67% to 17.19% with a maximum coefficient of variation value of 9.3% (Mfr.3).

The initial rate of absorption (IRA) values for the 4 manufacturers ranged from 0.61 g/cm$^2$/min to 0.38 g/cm$^2$/min, and coefficient of variation values ranged from 12.21% to 31.97%; the high coefficient of variation values are attributed to the lack of quality control during the manufacturing process of the fired clay brick units using manual methods. The types of mortars, cement: sand ratio and resistance to compression in mortar cubes used in the present investigation, is given in Table 1.

**Table 1.** Types of mortars and compressive strengths.

| Types of mortars | Cement: sand ratio | Compressive strength (MPa) |
|---|---|---|
| M | 1:1 | 21.94 |
| S | 1:2 | 14.56 |
| N | 1:3 | 12.95 |

Natural river sand with a fineness modulus of 2.55 was used for the mortars; the flexural test is applied at a uniform rate (8 mm/min was adopted for this research) so that the total load is applied in no less than 1 minute or no more than 3 minutes. The flexural strength ($F_g$) of the brick-mortar joint was established as indicated [7], and indicated in the 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 (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) y $d$ is the average thickness of the cross-section of the failure surface (mm).

## 3. Results and discussions

The behavior of the compressive strength of fired solid clay units (MPa) vs. deformation (mm) by manufacturer (Mfr.) under study for the municipality of Ocaña, Colombia, is presented below, see Figure 1. Samples are indicated as M the next digit indicates the manufacturer separated by a dash to indicate the specimen number.

Five compressive strength ($f'_{cu}$) tests were carried out on mortar joints for Mfr.1, presenting maximum values of compressive strength vary from 7.7 MPa to 15.0 MPa. After the maximum compressive strength occurs, there are increases in deformation ($\epsilon$) with loss of compressive strength, this was due to a loss of stiffness product of cracking before collapse. The estimated zone with maximum compressive strength is presented at a strain $\leq$ 5 mm and its complying with American Society for Testing and Materials (ASTM), ASTM C1072 standard [7], "Norma Técnica Colombiana (NTC)", NTC 4017 [8] and NTC 3329 [9] standard. The dispersion in maximum compressive strength in fired clay masonry units is important and presents a wide range of possible values of maximum compressive strength.

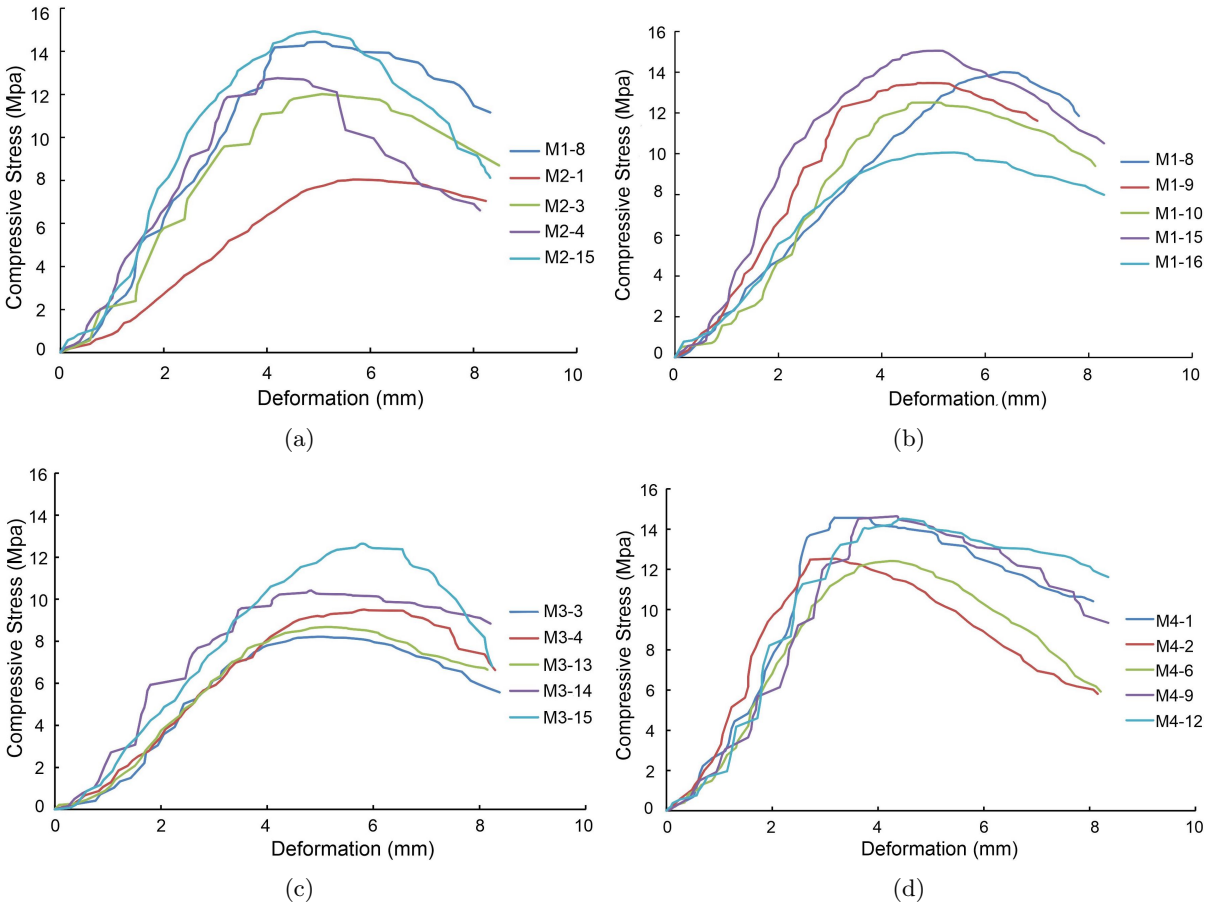



**Figure 1.** Compressive strength behavior; (a) Mfr.1, (b) Mfr.2, (c) Mfr.3, and (d) Mfr.4.

Mfr.2 has a more homogeneous $\epsilon$ vs $f'_{cu}$ behavior with respect to Mfr.1 mainly for $0 \text{ mm} \leqslant \epsilon \leqslant 5.3 \text{ mm}$, since it has a lower dispersion behavior. Mfr.3 has a behavior $\epsilon$ vs $f'_{cu}$ with a lower variation than that presented by Mfr.1 and Mfr.2. However, this is the manufacturer that presents the lowest maximum compressive strength in masonry joints. The Mfr. showing better $f'_{cu}$, results, lower dispersion in the whole $\epsilon$ vs $f'_{cu}$ behavior and similar upward and downward slopes is Mfr.4, possibly due to sufficient firing.

The envelope curve of the behavior of the compressive strength of fired solid clay units (MPa) vs deformation (mm), is presented in Figure 2. The average behavior is defined by a continuous line, as well as the confidence interval $\mu \pm \sigma$. Figure 2 shows the high dispersion especially between 3 mm and 5 mm for the deformation, this is due to the high variation in the compressive strength of solid fired clay units, as well as the compressive strength of mortar.

Figure 3 shows the results of the compressive strength of mortar cubes ($f_m$) versus the average flexural strength of the bond between the mortar and the solid clay brick ($F_g$), for Mfr.1 to Mfr.4. Mfr.1 has a direct relationship between $f_m$ and $F_g$, although it presents a double slope in the two sections shown in Figure 3, this is due to the high dispersion in the $f_m$ mainly in its maximum strength, see Figure 1(a). Mfr.2 presents higher $F_g$ values than the other manufacturers for an $f_m = 10.22$ MPa (this corresponds to type S mortar according to NSR-10) [10], although for the compressive strengths of mortar cubes $\geq 15.00$ MPa the tendency is positive, that is, increasing. Mfr.3 does not show changes in the compressive strength range of mortar cubes between 10.22 Mpa and 15.00 MPa; therefore, Mfr.3 is not affected by the strength of the mortar, only for values higher than 15.00 MPa. Mfr.4 $F_g$ is affected by $f_m$, which is in accordance with the literature [11–14]. The average values of $F_g$ vs. $f_m$ shown in Figure 3, are the expected behavior; a linear regression fits the obtained results and is presented with a coefficient of determination $R^2$ equal to 0.9104.

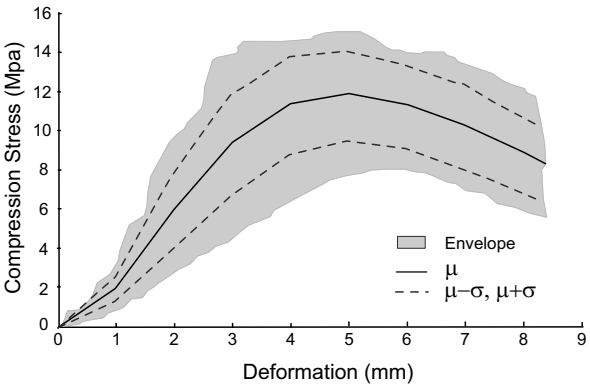



**Figure 2.** Compressive strength envelope.

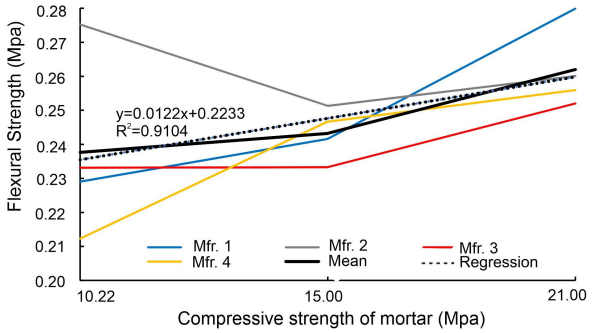



**Figure 3.** Flexural strength as a function of the compressive strength of the mortar.

## 4. Conclusions

There is a direct relationship between the flexural strength of the bond between the mortar and the solid clay brick with respect to the compressive strength of the mortar; that is, the higher the compressive strength of the mortar, the higher the flexural strength. From the analysis of Figure 1 and Figure 3 it can be inferred that the higher the compressive strength of fired solid clay masonry units, the higher the flexural strength of the joint, which is the case for manufacturer 4. It can be concluded that the physics of the flexural strength behavior of the joint between the bonding mortar and the solid clay brick depends on both the compressive strength of the mortar and the compressive strength of the solid fired clay units. It is possible to improve the flexural strength of the joint by using small perforations to the brick to increase the flexural strength.

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