Alternatives for improving the compressive strength of clay-based bricks

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Abstract. In this work three alternatives to improve the compressive strength of clay-based bricks were evaluated. Four mixtures were prepared: the control with only CLAY (without any treatment), one single mixture with the ground and screened clay (CLAYGS), one binary mixture in which CLAYGS was partially replaced by fly ash (FA) and one ternary mixture in which CLAYGS was partially replaced by FA plus Sugar Cane Bagasse Ash (SCBA). Apparent densities and porosities (ASTM C-20), initial rates of absorption (ASTM C-67) and compressive strengths (ASTM C-67) were determined. The results showed that the use of CLAYGS has positive effects on the density, porosity and compressive strength of bricks made with this material. Bricks made with CLAYGS were 23.08% denser, 20% less porous and 64.41% more resistant to compression than control bricks. According to the ASTM C-62 standard, the bricks obtained correspond to the MW grade. The partial replacement of CLAYGS with 20% FA improves the quality of bricks made only with CLAYGS and with CLAY. According to the ASTM C 62 standard, the bricks made with binary mixture (CLAYGS+FA) have the compressive strength required to be considered SW grade bricks. The addition of SCBA in binary bricks negatively affects their compressive strength.

1. Introduction

Fired clay bricks are widely used materials in the construction industry. This is mainly due to their simple manufacturing process and the availability and low cost of their raw materials [1]. The history of fired clay bricks is almost 6000 years old and traces of that have been found in Babylonia [2]. Despite being one of the oldest building materials, only a few countries have developed technical processes to improve their quality and produce them industrially [3]. Unfortunately, in developing countries, the elaboration and production of clay bricks is still carried out with almost ancient or artisan techniques. Traditional kilns generally used in artisanal activity have intermittent or batch production; they are direct-fired, rectangular and open to the atmosphere. Most artisans generally do not have sufficient economic and technical resources to improve the quality of their products. The properties of clay bricks vary depending on various factors including raw material properties, manufacturing method and burning process [4]. The lack of technical knowledge, the characteristics of the kilns and the lack of innovation in the manufacturing process cause the bricks produced in a traditional way to be low quality. Under these conditions, the compressive strengths of the bricks
produced usually correspond to NW grade (Negligible Weathering) and rarely to MW grade (Moderate Weathering) according to ASTM C62 standards [5].

On the other hand, the resistance of a material is defined as the ability to resist stresses without failure [6]. Compressive strength (CS) of construction materials is the most common measure that construction professionals use to design buildings, walls and other structures, as well as to validate the quality of their components. The CS usually gives a general idea of the quality of the bricks as it is directly related to the bricks internal structure after firing. In Mexico, there are some works that have been developed in order to improve the quality of artisan bricks. Ordoñez [7] produced MW grade bricks. She used a mixture of 40% clay soil plus 60% sandy soil and 25% humidity to make bricks, and fired them at 1100 °C. Palmas [8] recently reported that the incorporation of 3% of reactive glass improved the compressive strength from 12 to 18 MPa in bricks sintered at 900° C and made with raw materials that did not contain clay minerals in their mineralogy.

The objective of this work is to evaluate three alternatives to improve the compressive strength of clay-based bricks. The first alternative is to apply a treatment to the clay (grinding and screening) to make the bricks with this material; the second alternative is to partially replace the clay (obtained in alternative one) with 20% fly ash, and the third one is to partially replace the clay (obtained in alternative one) by the combination of 20% fly ash + 10% of sugar cane bagasse ash.

2. Experimental program

2.1 Materials and Methods

The clay (CLAY) was collected from a local bank located in Santa Lucía del Camino in the state of Oaxaca, Mexico. The treatment consisted of the following: After drying the clay for 24 hrs in an electric oven at 105 °C, it was ground for 40 minutes in a 17-liter capacity ball mill. Subsequently, it was screened by ASTM No. 100 mesh (150 µm) for 5 minutes. With this treatment, only 10% of clay passed the mesh No. 100, therefore, the material retained in the mesh was ground again for 120 minutes and screened through the same mesh; with this process, the yield was 90% of clay with maximum particle size of 150 µm, Figure 1. The material used for the first alternative was formed with 15% screened clay plus 85% ground and screened clay; this clay was designated as CLAYGS. The specific gravity of the CLAYGS was 2.95.

The fly ash (FA) was obtained from the “José Lopez Portillo” coal-fired power plant located in the state of Coahuila, Mexico. FA is generated during the combustion of mineral coal for energy production. The sugar cane bagasse ash (SCBA) was collected from the Constancia sugarcane mill, located in Tezonapa, Veracruz Mexico. SCBA is generated as a combustion byproduct of sugar cane bagasse. The collected ashes were dried for 24 hours in an electric oven at 105°C; after that, they were sieved using a sieve No. 200 (75 µm) for four minutes. The specific gravities of the ashes were 2.27 and 2.24, respectively. The chemical composition of the clay and ash was determined by the X-ray fluorescence (XRF) method with an Epsilon 3 XL energy dispersive X-Ray spectrometer. The chemical compositions of the clay and ash used in this study are summarized in Table 1.
Table 1. Chemical analysis of the materials used, %

| Element  | Oxide (%) | (Al₂O₃) | (CaO) | (Fe₂O₃) | (K₂O) | (MgO) | (MnO) | (Na₂O) | (P₂O₅) | (SiO₂) | (TiO₂) | LOI |
|----------|-----------|---------|-------|---------|------|------|------|-------|-------|-------|-------|------|
| CLAY GS  | 19.50     | 4.20    | 3.54  | 2.50    | 1.20 | 0.10 | 1.26 | 0.80  | 65.30 | 1.63  | 3.42  |
| FA       | 13.14     | 0.92    | 2.58  | 0.76    | 1.20 | 0.30 | 1.60 | 0.00  | 77.42 | 2.61  | 2.38  |
| SCBA     | 14.61     | 2.36    | 5.04  | 3.29    | 1.43 | 0.18 | 1.57 | 0.85  | 56.37 | 0.96  | 10.53 |

LOI (Lost of Ignition obtained at 750°C)

The clay and ash mineral phases were identified by X-ray diffraction, using a Bruker D8 Advance® diffractometer. The main mineral phases identified in the CLAY GS were montmorillonite- chlorite, quartz, albite, albite calcian ordered and orthoclase; quartz and mullite were found in FA and finally, quartz and albite calcian ordered were identified in the SCBC.

Four mixtures were prepared: the control with only CLAY (without any treatment), another mixture only with the treated clay (CLAY GS), one binary mixture in which CLAY GS was partially replaced by FA and one ternary in which CLAY GS was partially replaced by FA plus SCBA. Mixture compositions are shown in Table 2.

Table 2. Mixture composition (wt. %)

| Description                   | Mixture | CLAY | CLAY GS | FA | SCBA |
|-------------------------------|---------|------|---------|----|------|
| Control (Clay without treatment) | C       | 100  |         |    |      |
| Simple (Clay with treatment)   | Sₜ      |      | 100     |    |      |
| Binary (Clay with treatment + FA) | B      | 80   | 20      |    |      |
| Ternary (Clay with treatment + FA+SCBA) | T     | 70   | 20      | 10 |      |

FA: Fly ash, SCBA: sugarcane bagasse ash

2.2 Samples preparation

The clay and ashes were dry mixed using an ELVEC®15-liter mixing machine for five minutes; water was then added and mixed for 15 more minutes. Subsequently, the Atterberg consistency limits of all mixtures were evaluated in accordance with the ASTM D4318-10. Fifteen bricks were fabricated per mixture. The bricks were cast using the manual molding technique. Freshly prepared wet bricks were allowed to dry for 10 days at room temperature to harden enough to be transported to the kiln undamaged. Afterwards, bricks were placed in kiln.

In order to have control over the firing temperature (1000°C), the firing was carried out in a kiln used in the production of ceramic pieces powered by LP gas for 7 h at a heating rate of 2.0°C/min. During the firing process the temperature of the oven was monitored with K-type thermocouples, with one located at the front of the oven and the other at the back. Both thermocouples were connected to an Autonics pyrometer, model TZN4S-14R®, to control the firing temperature, Figure 2.

![Figure 2. Bricks manufacturing](image)

a) Manual molding, b) Drying at room temperature, c) Firing, d) Firing bricks

2.3 Test methodology

Apparent densities and porosities (ASTM C-20) Figures 3, initial rates of absorption (IRA) (ASTM C-67) Figure 4, and compressive strengths (ASTM C-67) were determined. The compressive strength was estimated using an ELVEC® model E659-5 compression machine, Figure 5.
3. Results

3.1 Apparent densities and porosities

Figure 6 shows the results of apparent densities and porosities of fired bricks made with the four mixtures. The average density of fired bricks made with control mixture was approximately 2.0 g/cm$^3$ and coincides with what is reported in the literature [9]. The bricks made with the single mixture presented the highest densities (23.08% denser than the control); the grinding and screening treatment were favorable since, during the manufacturing process, there was better packing of the mixture, resulting in a denser material. The densities of the bricks made with the binary mixture were slightly lower than the density of the bricks made with single mixture; this coincides with that reported by Xu et al. [10], who affirm that the particle size influences the properties of the bricks since the sintering force is inversely proportional to the radius of the particles. The bricks made with the ternary mixture presented the lowest density, which is a consequence of the partial substitution of the clay the with the ashes that have lower densities with respect to the density of the clay.

Figure 6 also shows the results of apparent porosity of the fired bricks. They are related to the results of the apparent density tests. It is observed that bricks made with single and binary mixtures have less porosity than those made with ternary mixture (20% and 24.8% respectively), probably due to the formation of low-silica-content glass with other oxides present in FA, which has a lower viscosity and easily flows to fill the open pores [11]. The bricks made with ternary mixture have the largest porosity of all mixtures. The generation of gas from the decomposition of carbonaceous matter contained in SCBA generates more porosity [12]; the LOI (10.53%) of the SCBA is higher than those of FA and CLAYGS.

3.2 Initial rates of absorption

Figure 7 shows the results of initial rate of absorption for the bricks made with four mixtures. It was observed that the bricks made with control and ternary mixture present a higher percentage of
absorption than the simple and binary mixtures; this occurs because absorption is a property directly related to the microstructure of the material and to the volume fraction of open pores.

**Figure 7.** Bricks initial rate of absorption

The bricks made with the binary mixture had a lower initial rate of absorption; this may be caused by the partial closure of open pores or by a decrease in the interconnectivity between pores due to the sintering process [13]. All the bricks exceeded the initial rate of absorption established by the ASTM C62 (0.15 g/min/cm²); therefore, they should be moistened 8-24 h before being placed.

### 3.3 Compressive strength

The values of the compressive strength (CS) of the bricks are shown in Figure 8. It can be observed that the control bricks had the minimum compressive strength value recommended by the ASTM C62 to be considered NW grade bricks. Otherwise, the bricks made with single and binary mixtures had higher compressive strength than the control mixture (65.41% and 78.33%, respectively). The compressive strengths obtained by these bricks allow them to be classified as MW (Moderate Weathering) and SW (Severe Weathering) grade ASTM C62, respectively.

**Figure 8.** Compressive strength of fired bricks

This is the consequence of better packing (due to the particle size) during the elaboration and firing processes. The substitution of clay for FA was favorable, as it increased the compressive strength of the bricks; this is attributed to the presence of TiO₂ that acts as a nucleating agent in the glass ceramic formation [14] as well as their mullite content. Kausik et al. [11] described mullite as a high hardness mineral that contributes to increasing the mechanical strength of ceramic bodies. In the case of bricks made with ternary mix, the substitution of SCABA with clay had negative effects, as it reduced the compressive strength of the bricks. As previously stated, the higher percentage of porosity in these bricks could be due to their high content of carbonaceous matter and the irregular shape of the UtSCBA particles, which generated less packing. The concentration of pressure due to the open pores...
can cause the loss of structural compaction and a decrease in the compressive strength of the bricks [13]. These results are supported by and directly related to the results of the density and apparent porosity tests.

4. Conclusions
The use of ground clay and screened with the No.100 mesh (CLAY GS) has positive effects on the density, porosity and compressive strength of bricks made with this material. Bricks made with CLAY GS were 23.08% denser, 20% less porous and 64.41% more resistant to compression stresses than control bricks. According to the ASTM C 62 standard, the bricks obtained correspond to the MW grade.

The partial replacement of CLAY GS by 20% CV improves the quality of bricks made only with CLAY GS and CLAY. With this mixture, bricks 12.92% and 78.33% more resistant to compression stresses than bricks made with CLAY GS and CLAY, respectively, are obtained. According to the ASTM C 62 standard, the bricks made with binary mixture (CLAYGS+FA) have the compressive strength required to be considered SW grade bricks.

The addition of SCBA in binary bricks negatively affects their resistance to compression. The use of a kiln with a controllable temperature allows obtaining bricks with better physical and mechanical properties than bricks fired in an artisanal kiln.

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