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Implementation of an automated dryer with solar collector

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Abstract. This research work consists of the development of an automated sustainable drying system using forced and preheated air to reduce the production time of handmade bricks, so a dryer witha solar collector was implemented to take advantage of the energy from solar radiation. A virtualinstrument was developed, which allows to visualize the variables of temperature and humidityinside the drying chamber, additionally a temperature control was implemented, this control allows the system to maintain a constant temperature during the drying process. Samples were taken from the production of the brick kiln "El Tejar" and dried by this device, thenthe drying times and their physical and mechanical properties were compared, finding that the bricks dried with the proposed prototype retained these properties. As for the compressive strength tests for samples of both processes was around 30.6 Kgf/cm² and 31.2 Kgf/cm², the deflection resistance was around 1.2 Kgf/cm² and 1.3 Kgf/cm², the initial absorption rate was around 0.3 g/cm²/min and 0.4 g/cm²/min, and finally the percentage of water absorption for both processes were around 12.9% and 13.1%. The difference lies in the drying times, since drying in the artisanal brick kilns takes about 15 days in the proposed dryer takes 9 days, resulting in a decrease of 40% in this process.

1. Introduction

Ceramic bricks are a fundamental part of the construction industry, these bricks make up different structures in buildings, in which they are subjected to impacts, vibrations and high compressions, therefore, their physical, chemical and geometric characteristics must comply with specific norms and standards, to be considered quality products necessary for their use; it is of vital importance to comply with all the necessary characteristics that a strict control is applied throughout the manufacturing process, especially the drying process as this is the one that directly affects their properties and is more sensitive to changes [1,2]. The drying process consists of removing moisture from a material, involving the phenomena of heat and mass transfer simultaneously; mass transfer happens when the solid loses moisture, and heat transfer occurs when the environment (air) delivers heat to the solid [3].

In this document a problem found in the production of handmade bricks is registered, which is the dryingtime of these, since by its handmade production no drying method is applied, they are simply arranged to be dried in the sun. It was found that this part of the process takes from 15 days to 22 days, that is where the idea of building a prototype that decreases the drying time, improving the production times of theseis raised.

With the implementation of the brick dryer prototype, questions arise such as does the implementation of the prototype decrease the drying time of the bricks and does the application of a drying method affectthe physical and mechanical properties of the bricks? To answer these questions, samples were dried inthe prototype and their weight was recorded daily until a loss of 17% to 20% of their weight was reached,resulting in a loss of moisture, all this in order to verify the decrease in drying time, resulting in a 40%decrease in drying time; now to verify the conservation of the physical and mechanical properties of thebricks were made to the samples (both those dried with the prototype and those dried in the brick kiln) tests of compressive strength, bending tests of absorption rate and water absorption, resulting in the conservation of these properties.

It is common to find bricks of different dimensions, shapes, and materials according to the requirementsof the industry; this has been possible thanks to the advances in the manufacturing process; even with the advances and innovation in the process of making bricks it is common to find artisanal factories, as these processes are part of the tradition and culture of many regions, a study in Colombia shows that there are 1343 brick kilns and 77% of them perform their process by hand [4], according to "Plan Básico de Ordenamiento Territorial (PBOT)" of the municipality of Ocaña, Colombia, it has around 30 artisanal clay brick factories, also known as "Chircales" [5].

The main drawback in the production of handmade bricks is the long drying times that vary from five to seven days depending on weather conditions, since this process takes advantage of the natural actionof the sun and the wind, so that on cloudy and rainy days the drying process stops, delaying the production process [6], by not having control over the climatic conditions, the drying of the bricks is not always done in the best way, since it is not possible to expel the necessary amount of moisture from inside the brick, causingimperfections at the time of firing and many bricks cannot be sold, generating losses for these small businesses [7], taking into account that most of the time of the production process is spent in the drying stage, it is necessary to develop a system that allows the artisanal producer to reduce production times without a significant increase in costs.

2. Materials and methods

There are different types of dryers, such as oven dryers, tray dryers, tunnel dryers, conveyor belt dryers, among others. For this research a dryer or drying chamber with forced air injection was sectioned, and as an additional component a solar collector was used to heat the air that enters the chamber; taking into account the characteristics of the production of handmade bricks, this model was chosen as it is relatively economical compared to those previously mentioned, since the energy required for its operation is relatively low, since most of the energy used in the drying process comes from the sun [8,9].

Figure 1 shows the model proposed using Xflow software [10] considering the amount of samples to dry and the disposition inside it, the dryer was built to store two trays with six samples each one. The basic configuration of a forced air dryer is a special chamber where the product is placed, it is equipped with a hot air generator system and a series of ducts. Water is removed from the surface of the material and carried out in one operation; the air is heated as it enters the dryer by a solar collector [11].

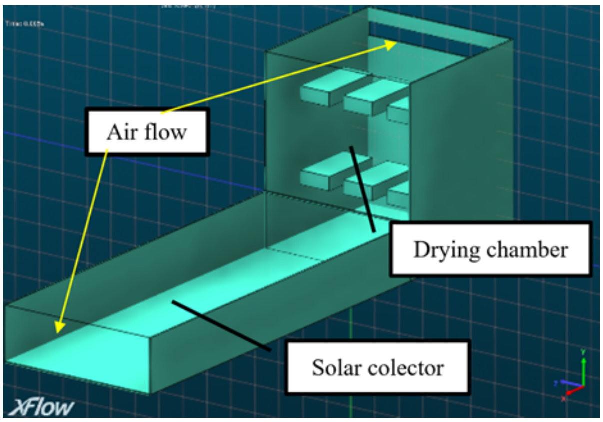

Figure 1. Model of the proposed dryer.

3. Results and discussions
The validation process of the proposed system consisted of taking samples of wet bricks from the artisanal brick kiln “El Estanco”, five samples were taken and dried in the proposed prototype, all this to take the time it took for the sample to reach the percentage of moisture suitable for firing. The objective of this, besides verifying if there is a decrease in the drying time, was to check if these after the firing process retained the physical-mechanical properties.

3.1. Performance analysis of the proposed system
To measure the performance of the proposed system against the traditional process of artisanal brick kilns, 5 samples were labeled and weighed daily until they reached a weight loss ranging between 17% and 20%, which indicates that the brick isready to go to the kiln. Figure 2 and Figure 3 show graphically the daily drying process; it can be said that when comparing the process of drying in the open air which has a duration of approximately 15 days for the best of the cases, the drying by means of the proposed prototype had a duration of 9 days, which results in a reduction of 40% in the drying time.

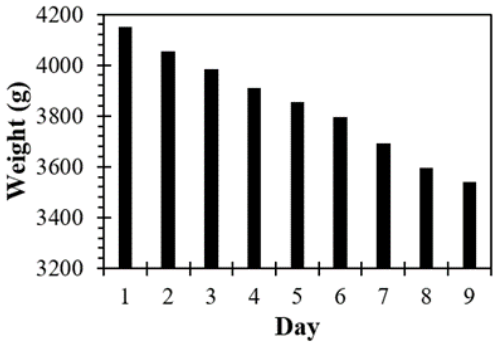

Figure 2. Daily weight loss for sample 1.

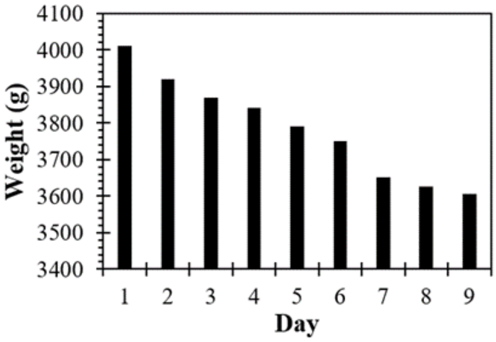

Figure 3. Daily weight loss for sample 2.

3.2. Physical testing of samples
In civil engineering, the compression test is a procedure focused on determining the resistance of a material, as well as its deformation under compressive stress; this test is performed on concrete and metals, or on any material whose resistance is to be measured. The purpose of this test is to measure the compressive strength of the bricks dried by means of the prototype and the bricks dried in the open air and to compare their physical and mechanical properties; this test is carried out on the previously fired bricks, which have the same dimensions.

Figure 4 shows graphically the data of the test carried out on the bricks dried in the prototype (2 kind of samples). It should be noted that the data are around 30.6 kgf/cm^2 presenting a tendency around this point [12,13]. Also Figure 4 exposed the data of the test carried out on the bricks dried in the open air. It should be noted that the data are around 31.21 kgf/cm^2 presenting a tendency around this point.

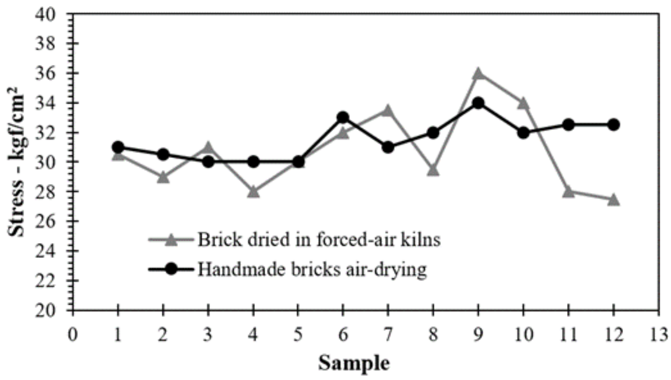

Figure 4. Compressive strength for both kind samples.

On the other hand, the bending test allows to evaluate the bending behavior of a material, bending is the deformation of an element on a direction perpendicular to its longitudinal axis; considering the above, the following variables were calculated.

3.2.1 Stress: This mechanical property is calculated considering the resistance offered by a unit area (A) of the material of which a member is made to an external applied load (F) using Equation (1), where stress is represented by σ [14].

$$\sigma = \frac{F}{A}. \tag{1}$$

3.2.2. Deformation: It is defined as the change on the size or shape of the element under analysis due to internal stresses produced by forces applied on it or the occurrence of thermal expansion.

3.2.3. Elastic deformation: it is the one that allows the element to return to its initial dimensions before the test; it is reversible after removing the loads that generate its deformation.

3.2.4. Plastic deformation: it is irreversible or permanent. A mode of deformation in which the material does not return to its original shape after removal of the applied load.

3.2.5. Initial absorption rate and water absorption. Among the physical properties studied in the bricks are the initial absorption rate and water absorption. The initial absorption rate (IAR), given in g/cm²/min, measures the amount of water absorbed by the brick in one minute, since the pores of the bricks function as capillaries in the presence of water; when grout is placed in the units, it sucks some of the water out of the mortar, which affects its bond and the consistency of the mortar. Poor bond affects masonry strength, durability, and water penetration.

The test consisted of determining the dry mass and the final mass of the test, recording the IAR which was calculated using Equation (2). Notice that m_f is the final mass of brick, m_i is the initial mass of brick, and $A_{contact}$ is the contact area of the sample with water.

$$IAR = \frac{m_f - m_i}{A_{contact}} \times 100\ \%. \tag{2}$$

The water absorption capacity (C_{wa}) of a brick is defined as the ratio of the weight of water it absorbs to its own weight when dry, expressed in percent; to calculate this factor, Equation (3) is used, where P_{Sat} is the weight of water saturated brick, and P_{Sec} is the weight of dry brick.

$$C_{wa} = \frac{P_{Sat} - P_{Sec}}{P_{Sec}} \times 100\ \%. \tag{3}$$

3.3. Design considerations

The first variable to consider in this analysis is the drying time, this process in the handmade brick kilns is done outdoors, if we compare the best case that occurs in summer when there is greater exposure to the sun, the process takes about 15 days; when comparing the drying time of the handmade brick kilns with the drying time in the prototype, a 40% reduction of the drying time is registered, since with the prototype the samples can be dried in a period of 9 days.

The other variables to be taken into account are those related to the conservation of the physical and mechanical properties of the bricks, so the tests were carried out on samples dried in the brick kiln and samples dried with the prototype.

From the above it can be said that the properties are preserved, since the strength data of the samples dried in the brick kiln and the samples dried in the prototype are similar, since these failed on average at 30.6 kgf/cm^2 and 31.2 kgf/cm^2 , in terms of bending, this property is also preserved since these failed on average at 1.2 kgf/cm^2 and 1.3 kgf/cm^2 , this property is also conserved since they failed in average at 1.2 kgf/cm^2 and 1.3 kgf/cm^2, the IAR is also conserved since they are in average around 0.39 g/cm²/min and 0.45 g/cm²/min and finally the water absorption is also conserved since they are in average around 12.98% and 13.19%, respectively.

The mechanical behavior to compression of the samples, both dried in forced air and dried in the sun; a variation is denoted in each of the tested samples, where it can be concluded that none of them presents a linear mechanical behavior since these parameters are directly involved with the initial phases of production of the handmade brick and not with the drying system.

The variation of the established result for the initial rate of water absorption per minute shows a higher absorption when the handmade brick is dried in the prototype, as evidenced in Figure 5; when we talk about the absorption of conventional air-dried brick, it was found that the absorption is lower, but it does not present a dispersion of data. The percentage of water absorption of the handmade brick is one of the parameters that has greater influence, since this determines the use to be used either for interiors or exteriors.

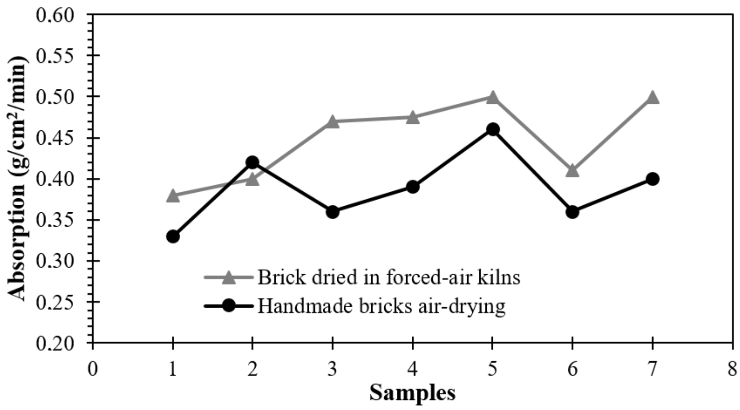

Figure 5. Test results, IAR, applied to the bricks.

4. Conclusions

The problem initially raised, regarding the drying of the bricks, and the objective was to develop a sustainable drying system using forced and preheated air to reduce the production time of handmade clay bricks. In this regard, it can be said that the objective was fully met, since a prototype dryer was built, which uses air heated by a solar collector, the implementation of this dryer also meets the stipulated in terms of reducing the drying time of the brick, since this was reduced by 40%.

The resistance to compression, bending, water absorption, among other physical tests applied to the bricks dried in the brick kiln as well as those dried in the dryer, are in a very close range of these physical and mechanical characteristics, concluding that these are not negatively affected by using the prototype. It can be said that even though the brick kilns located in “El Estanco” have experience in the brick manufacturing process, this does not guarantee a homogeneous linear mechanical strength in all their samples because they do not have direct control over the variables of the brick production process, among other factors.

It can also be said that, when comparing the traditional drying method of the artisan brick kilns, with the drying by means of the proposed prototype, it is evident that in the traditional method there is no control of the variables involved in the drying process, which when comparing this method with the proposed drying method provides the samples with a controlled environment, reducing the losses of material

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