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Design and manufacture of a scale chamber prototype with variation of humidity and temperature for curing fly ash/slag based-alkaly activated concretes

Diseño y fabricación de un prototipo a escala de una cámara con variación de humedad y temperatura para curado de concretos de activación alcalina elaborados a partir de mezclas de escoria siderúrgica y cenizas volantes

Carlos Daniel Hernández-Montiel[a], Willian Arnulfo Aperador-Chaparro[b*], Manuel Jonathan Pinzón-Cárdenas[c], Jhon Wilmar Cárdenas-Pulido[d].

[a]*Ingeniero en Mecatrónica, Universidad Militar Nueva Granada, Bogotá Colombia. orcid.org/0000-0002-0376-5047*
[b]*Doctorado en Ingeniería con énfasis en Ingeniería de Materiales, Universidad Militar Nueva Granada, Bogotá Colombia. orcid.org/0000-0003-1778-0851*
[c]*Ingeniero en Mecatrónica, Universidad Militar Nueva Granada, Bogotá Colombia. orcid.org/0000-0003-0300-1837*
[d]*Ingeniero Civil, Universidad Militar Nueva Granada, Bogotá Colombia. orcid.org/0000-0003-4698-4896*

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ABSTRACT

The design and manufacture of a modular scale prototype of a chamber with variation of moisture and temperature for curing alkaly activated concretes based on mixtures of slag and fly ash was assessed, to be mounted directly on site; this study benefits the industrial sector in the development of new projects since it allows improving performance, reducing risks and transport costs in the manufacturing processes of the materials that are presented today. The device requires the integration of various mechanical and electronic elements together with knowledge in the area of control and programming for proper operation, in addition, a degree of precision is necessary to ensure optimum levels of strength in different types of concrete by alkaline activation, from the design and the good choice of materials in the manufacture of the chamber.

Keywords:
Ash
Curing
Moisture
Slag
Temperature

RESUMEN

El estudio realizado da a conocer el diseño y fabricación de un prototipo modular a escala, de una cámara con variación de humedad y temperatura para curado de concretos de activación alcalina; elaborado a partir de mezclas de escoria siderúrgica y cenizas volantes, para ser montado directamente en obra; el estudio beneficia al sector industrial en el desarrollo de nuevos proyectos a dado que permite mejorar el desempeño, reducir riesgos y costos de transporte en los procesos de fabricación de los materiales que se presentan en la actualidad. El dispositivo requiere de la integración de distintos elementos mecánicos y electrónicos junto con conocimientos en el área del control y la programación para su correcto funcionamiento, además, es necesario un grado de precisión para garantizar niveles óptimos de resistencia en los diferentes tipos de concreto por activación alcalina, a partir del diseño y la buena elección de los materiales en la fabricación de la cámara.

Palabras Clave:
Curado
Humedad
Temperatura
Escoria
Ceniza

Introduction

Regarding to the technical problems of the traditional Portland cement concrete, it is worth to remark those related to durability, reinforcement corrosion, frost resistance, sulfate attack, carbonation, and so on. [1],[2]. Thus, with the aim focused in contributing to the reduction of gas emissions into the atmosphere and to solve the problems of durability of Portland cement, it has been proposed the use of partial mineral additions to cement such as fly ash and blast furnace slag, whose manufacture does not generate a high energy consumption; and also it doesn´t emit too high polluting gases volumes and its filler effect and pozzolanic reaction help mitigate problems of conventional concrete durability [3].

In that sense, the Colombian metallurgical and energy industry generates substantial amounts of alternative raw materials to the cement (fly ash and steel slag), however, most of these are not fully exploited. In particular for each ton of coal that is burnt into a thermoelectric power plant, approximately 200 kg of fly ash are produced, and the consumption of the pulverized coal causes environmental problems due to the accumulation of fly ash in areas close to large deposits [4].

The ground granulated blast furnace slag (GBFS) and fly ash have been used traditionally as a partial substitute for ordinary portland cement within concrete mixtures, resulting in materials with comparable mechanical performance to blends 100% Portland cement [5]. Therefore, due to the increasing production at national and global levels of fly ash and blast furnace slag, it is necessary a higher recycling of these products. For this reason, the way of valorization of these residues can be its use for the total replacement of Portland cement in alternative concrete mixtures via alkaline activation.

Currently, the two big precursors for alkaly activated binders are blast furnace slag and fly ash from power plants and steel industry respectively, which are combined with chemical activators (hydroxides + silicates), provoking the transformation to particular gels with mechanical properties (aluminosilicate and calcium silicate hydrated gels) with a amorphous or semicrystalline configuration [4], [6]. In general, the curing of these alkali activated materials requires high temperatures, about 80 and 60 ° C and relative humidity around

***Corresponding author.**
E-mail address: william.aperador@unimilitar.edu.co (Willian Arnulfo Aperador Chaparro).

90% in a period of 24 hours. Currently the curing of these materials is carried out in specialized laboratories, due to the lack of curing methods that can be applied directly on site.

However, these curing conditions results practical for applications in plant for the production of prefabricated [7].

As mentioned, traditional methods for conventionally concrete curing in the construction field are oriented using readily wet environments, while for alkaly activated materials, curing procedures at high humidities and temperatures increase its transportation costs and limit its applicability. Consequently, this paper studies the design and manufacture of a chamber automated, modular curing, and which can be applied directly on site, to manufacture elements of various sizes by means alkaline activation [8].

The equipment mechanism proposed is to vary and monitor temperature conditions (up to 80 ° C) and moisture (up to 90% relative humidity) required for the curing process, in order to ensure a reduction in transport costs of alkaline activation material from the plant to the work. In this sense, by applying the technology of alkali activation, industrial wastes such as fly ash and blast furnace slag can be appropriately exploited and transformed into new materials with low energy consumption, characterized by presenting high durability and excellent mechanical performance [9].

Materials and Methods

Structural planning Several ideas were generated in terms of how to address the challenge of applying the curing process in a place other than a laboratory, so the conditions applicable in this particular case of environment differed from those applied in the laboratory, especially concerning the geometry which can be variable. In that sense, a modular solution that fitted to the geometry of the building, and also be easy to assemble and deject was proposed.

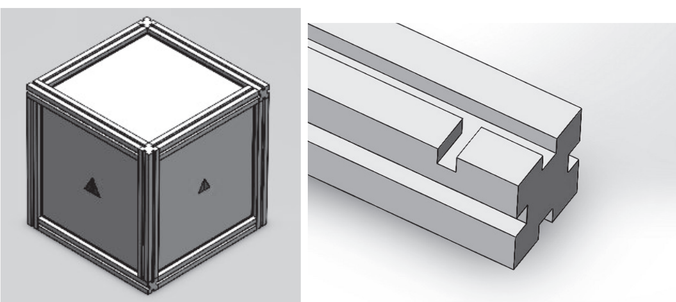

Figure 1. CAD chamber model

Based on the set conditions, the idea of a lamellar structure of low weight, assembled by plates bolted joint was raised, but the idea was dropped since the weight of the sheets and in some cases the height of the structure would be factors affecting its stability. For this reason, the need for the structure had structural support elements in which it was decided to allow the splined coupling studs of the sheets (Figure 1).

Focused on the aim of the project, that is, making a prototype, it was suggested that the geometry of this was adapted to the of size three mortar cubes (50x50x50 mm), and the measures presented were defined in the planes found in the attachments to this document [10].

The process of delineating the prototype elements planes was carried out by the mechanical design software SolidWorks, which allowed to notice that for the sheets coupling with the studs support, small channels at the ends became necessary of the main perpendicular to the longitudinal channels pareles to avoid mismatch dimensions by interference material.

Furthermore, analyzing the binding form between studs support and blades, it became clear that simply attaching the blades into the slots of the uprights wasn't enough since these connections generate a considerable amount of leakage; this situation impedes generation controlled environment as required for this purpose a sealed or otherwise with the least amount of leakage cavity, since these increase the amount of loss and result in defects in the curing process; From this, several options were discussed with the aim of reducing the number of leaks in the joints.

In that sense, within the scheme of alternatives there were glues and high density foams , but these alternatives were discarded quickly because these products would not allow elements of the prototype to be easily folded, it is then thought to use packaging rubber, analogous to the installation of the glass in a window frame, this idea was accepted because of its versatility and low cost [11].

The original dimensions of the channels were modified to suit the measurements of the rubber gaskets on the market and updated in the drawings, the latter being established as the design dimensions.

Selection of structural materials Taking as reference points the requirements of the curing process (working temperature between 60 and 80 ° C and a moisture of 90% for periods of 24 hours), the dimensional constraints imposed in the planning stage, and further having consider the logistical conditions of use of the prototype, which are the characteristics of a civil work, immediately discarded metallic materials, since the cost of these, with the required dimensions was high, and the weight of some of these negative impact on the prototype modular and versatile concept; this without difficulty would control moisture and temperature in a cavity with metal walls, since the capacity of water absorption and high thermal conductivity of these materials, would generate a rapid degradation of the prototype under the desired conditions of work [12].

For this reason it was evaluated for a moment the use of wood, but due to the high water absorption of this material it quickly gave up the idea, though, for cost, ease of packaging and versatility in installation process was a good option instead.

After analyzing several manufacturing processes utilizing analyzed Acrylonitrile Butadiene Styreneor ABS which is the most common plastic processes 3D printing and because of the availability of equipment 3D printing in the research group proceeded to the development of one of the support structures is the piece with the major material; this to evaluate the behavior of the material and printer at the time of making such structures.

The result of the test with the printer revealed that the size of the piece and the amount of material generated deformations in the structure so it was defected from this idea [11].

Having evaluated and discarded materials such as metal, wood and Acrylonitrile Butadiene Styrene, it was put to the use of polymers, which according to the data sheets consulted showing suitable values for the properties of interest in the design.

Then, it was proposed to use Nylon (PA, polyamide 6.6) due to its low thermal conductivity and excellent performance in external environments, and like this, other polymers such as polyurethane (PUR), polystyrene (PS) and high density polyethylene (HDPE).

In this regard, A review of the structural and mechanical properties (density) (rigidity, hardness, tensile strength) of the proposed polymers was done; it was concluded that the high density polyethylene (HDPE), comply fully with the requirements demanded by the process, because tolerate temperatures up to 120 ° C, and it has low water absorption in moisture environments and it is chemically inert; these features Nylon also had, but at a higher cost.

Drive Planning Different ideas about how the system responsible for ensuring within the chamber specified working conditions were raised. Taking into account that the conditions of application in this particular case differ from those in the laboratory essentially because geometry can be variable, a control solution type ON-OFF was proposed, as this allows variations in the plant which not alter significantly the conditions of control and depend on most of the power actuators.

Based on the set conditions, and a type on-off control it was set out which actuators assembly would be necessary, so it was initially thought in a system where entries were dependent on each other; so, it was thought of two mounting:

• Heating water by using electric resistance to the desired temperature and humidify the air by an ultrasonic nebulizer.

• Heating water with electric resistance at the desired temperature and using a pump and spray system to humidify the air.

These ideas were discarded because there were no techniques known assemblies specifications and also it was not possible to work separately moisture and temperature in case of special applications, so it was necessary to separate the system into two types to work in parallel (Figure 2), which are based in ensuring uniformity and heat with the use of a fan heater and through a spray misting system challenged to humidify the chamber [12].

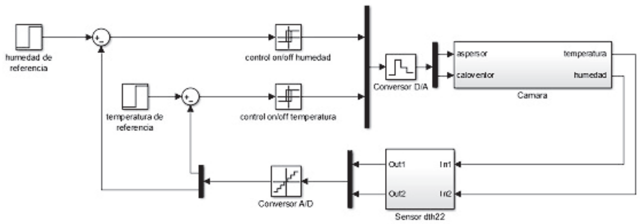

Figure 2. Process Control

Materials selection and manufacturing drive Taking as reference points the requirements of the curing process (working temperature between 60 and 80 ° C and a moisture of 90% for periods of 24 hours), the dimensional constraints imposed in the planning stage, taking into account logistic conditions of use of the prototype, which are the characteristics of a civil work, and also knowing the type of control with the assembly, it was proceeded to select the necessary elements for the phase variator which were:

• System temperature (Figure 3)

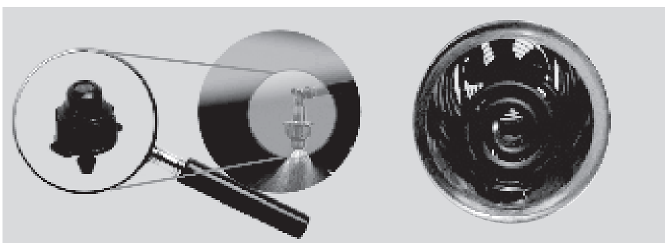

Figure 3. Actuators and caloventor

• The temperature system is based on the design of a caloventor which consists of an electrical resistance 110VAC 1.5A producing heat and a fan 2650 rpm (Figure 3) that drives the hot environment air, this design was the optimal based on finite element simulations that these properties determined for the actuators to be necessary to ensure uniformity and stability conditions inside the chamber (Figure 4).

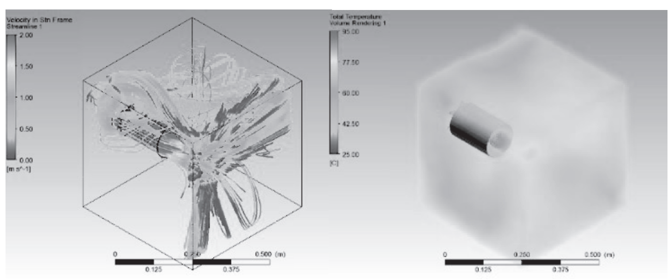

Figure 4. Temperature distribution

•***System humidity*** The moisture system is based on the design of a spray system nebulizer which consists of water driven by an electric pump to be a normally closed hydraulic solenoid 12vdc, which controls the water to flow to a spray nozzle dig fogger with spline mounted on a coupling which allows to humidify the air.

• ***Control*** Based on a control system type on / off the Microcontroller ATmega2560 data used and through dth22 digital temperature sensor and humidity which uses a capacitive humidity sensor and a thermistor to measure the surrounding air, as it was shown by a digital signal on data pin. The only drawback of this sensor is related to that you can only obtain new data once every 2 seconds, so readings can be made will be minimal every 2 seconds, but because the system is in use for 24 hours and stabilization time is 30 minutes, sampling is in the proper range for this application.

Figure 5. Cured Concretos Chamber

The data acquisition step is performed based on a serial communication via the microcontroller and a computer graphical interface in Matlab (Figura6) in which proceeds to display and monitor the behavior of the chamber.

Parallel the microcontroller depending on the reference temperature and humidity, so on / off along with a power conditioning integrated by optocouplers 4N35 and relays, enables two pins that control the actuators, in the case of system active temperature resistance and in the case of system activates electrovalve moisture, thus, it is efficiently controlled humidity and temperature in the chamber.

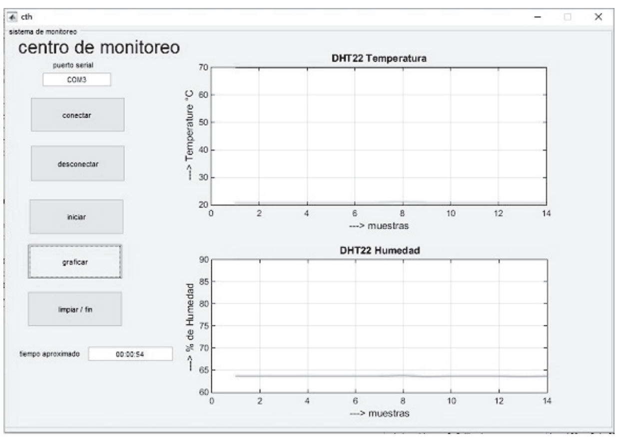

Figure 6. Monitoring interface

Results and Discussion

Performance tests of the chamber with mortar cubes NTC220

Aim: To determine the degree of variation in the resistance of mortar cubes of the same dosage based on steel slag and fly ash cured for 24 hours into the chamber against which were cured under laboratory conditions.

Procedure: It was done 3 trials in which the percentages of ash and slag were varied as the temperature conditions and humidity were performed as follows:

Table I. Testings

Test	TEMP. (° C)	Humidity	% Ash	% Human waste
1	70°C	90 % HR	100 %	100 %
2	70°C	90 % HR	50 %	50 %
3		90 % HR	0	100 %

For testing 6 cubes by test were manufactured based on Colombian Technical Standard NTC220 from which half were cured in the chamber and the other half in laboratory conditions.

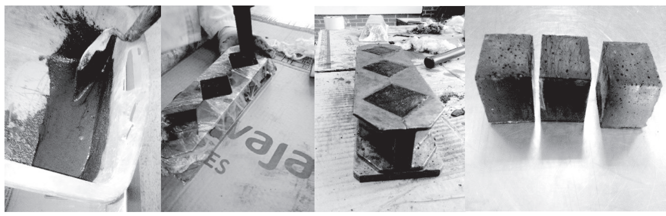

Figure 7. Mortar cubes making process

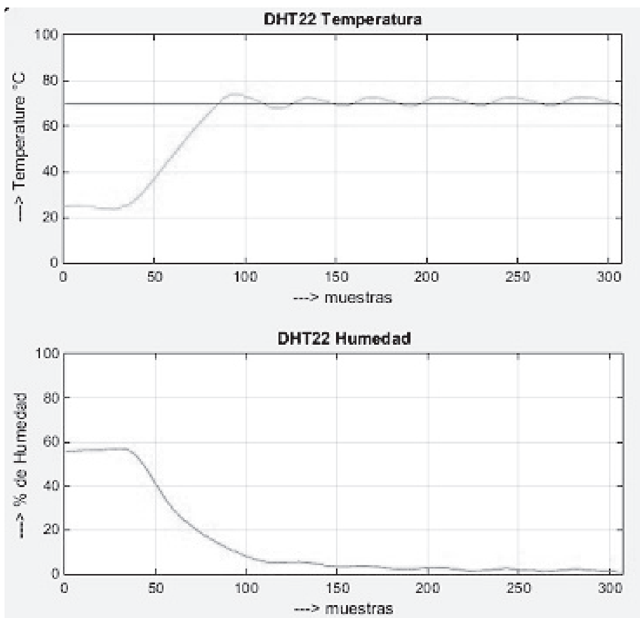

Figure 8. Test 1: Temperature 70 °

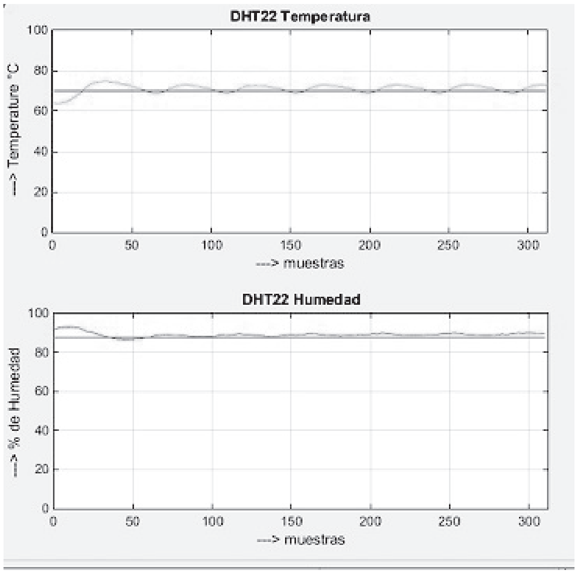

Figure 9. Test 2: Temperature 70 ° C - humidity 90%

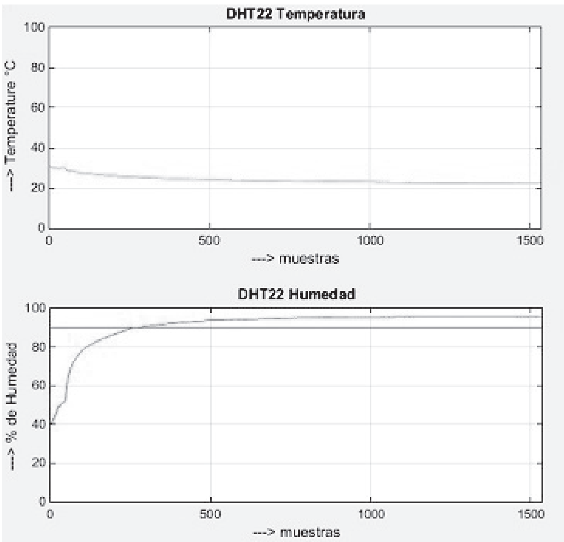

Figure 10. Test 3: Humidity 90%

After the curing process it was determined resistance to the mortar cubes understanding.

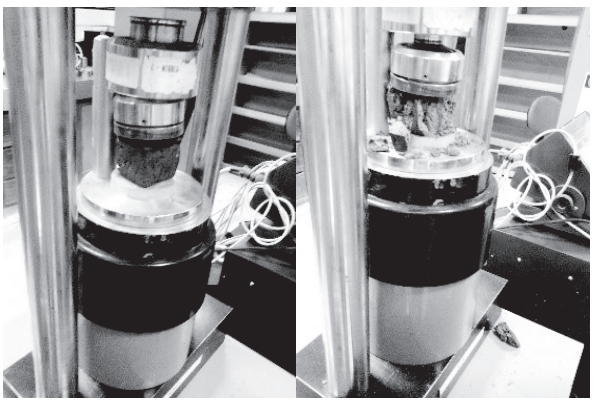

Figure 11. Compression test

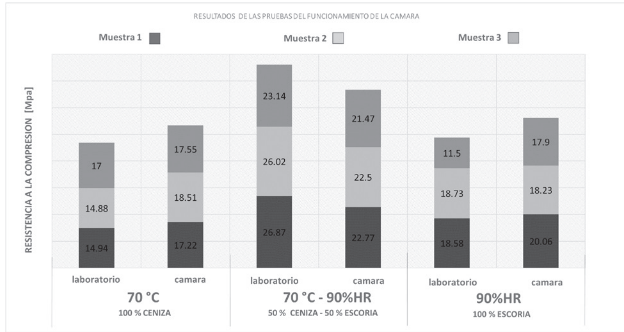

Figure 12. Test results to compression

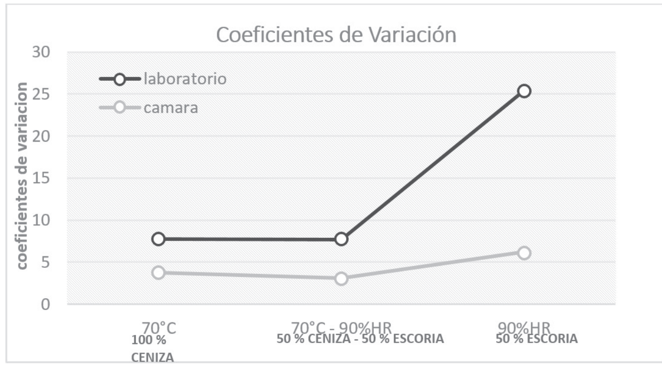

Figure 13. Variation coefficients

Tabla II. Laboratory Resistance Variance Percentage - Camera

% Ash	% Slag	% Lab variation–Chamber
100 %	0%	13,80 %
50%	50 %	12,21 %
0	100%	15,14 %

Results and Discussion

The chamber has different response types depending on the kind of test being performed; where the temperature control system used has a damped sub behavior with a steady-state error for the temperature of about ± 2.5 ° C and humidity to ± 2.5% RH, this is due in principle to the control operation, the ability to respond of the caloventor to the reference and the thermal properties and hydrophobic material [13],[14].

When the chamber is operating exclusively with humidity control, it is obtained a transient response over-damped and steady-state error of about ± 5% RH, because the humidification system is slow to respond since the structure has properties optimum sealing with the hydrophobic properties of the material, allow to maintain stable conditions in the chamber with minimum loss [14],[15].

The coefficients of variation of the compressive strength of mortar cubes cured in the chamber shown in (Figure 13) are lower compared to curing performed in the laboratory, since the chamber has better uniformity and stability regardless of values strength cubes or working conditions [15]-[17].

According to (Figure 12) it is confirmed that the mortar cubes, made with 50% slag and 50% fly ash, it is the ones which obtains higher values of compressive strength, compared to those made with other mortar mixtures [18]. The percentages of variation shown in (Table II) are not greater than 15%, this indicates that the variation between the results of the chamber and the laboratory are tolerable considering the industrial application to which the chamber will be put down, which will be useful for the field of civil engineering.

Conclusions

The device is capable of curing with high degree of stability and uniformity samples concrete made from slag and fly ash, obtaining compressive strengths comparable to alkaly activated materials cured in oven under laboratory conditions in a continuous period of 24 hours, or comparable to Portland cement materials with conventional curing, in continuous periods of 24 hours.

The variation coefficients obtained when comparing the compressive strength results between mortars cured in the laboratory and those cured in the chamber are low, because the fabricated chamber has better uniformity and stability in the operation regardless of the working conditions. The assembly of the device is easy to install and its monitoring interface which allows a simple and efficient interaction between the user and the device.

The development of the device is helpful for the analysis and projects developed by the scientific community and industry as it opens the possibility to develop a system on a real scale for building applications and reduce transportation costs and own costs when waste materials as replacements to Portland cement via alkaline activation.

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