Evaluation of internal curing effects on concrete

Evaluación de los efectos del curado interno del concreto

Sergio David Rodríguez-Torres[1] and Nancy Torres-Castellanos[2]

ABSTRACT

The objective of the present research was the evaluation of some fresh and hardened-state properties of concretes, in which coarse aggregates were partially replaced by lightweight ones previously saturated, in percentages of 15 % and 25 %. The lightweight aggregates were calcined clays and crushed clay bricks. In parallel, the effect of an internal curing agent composed of superabsorbent polymers (SAP) was evaluated. The properties evaluated in the fresh and hardened-state of concretes with a/c of 0,30 were: slum, air content, density, compression resistance, modulus of elasticity, initial superficial absorption and chlorine resistance. Results showed the efficiency of crushed clay bricks as internal curing, as well as the need for deeper research on the use of the evaluated lightweight aggregate as internal curing aggregate in concrete. Results indicate that the crushed clay bricks and the internal curing agent fulfill the behavior expected, in terms of strength and durability. However, the evaluated lightweight aggregate produces a reduction in the resistance and durability of the concrete. The observed behavior in strength and durability is especially variable for the age of 180 days, compared with conventional concretes.

Keywords: Absorption, Chloride resistance, Contraction, Internal curing, Lightweight aggregates, Lightweight concrete, Slum, Superabsorbent polymers (SAP).

RESUMEN

La presente investigacion tuvo como objetivo la evaluacion de algunas propiedades en estado fresco y endurecido de concretos, en los cuales se realizaron reemplazos parciales de agregado grueso por agregados ligeros previamente saturados, en porcentajes de 15 % y 25 %. Los agregados ligeros fueron arcillas calcinadas y ladrillos de arcilla triturados. Paralelamente, se evaluo el efecto de un agente de curado interno compuesto por polimeros super absorbentes (SAP). Las propiedades evaluadas en estado fresco y endurecido de los concretos con una relacion a/c de 0,30 fueron: asentamiento, contenido de aire, densidad, resistencia a compresion, modulo de elasticidad, tasa de absorcion superficial inicial y resistencia a cloruros. Los resultados mostraron la eficiencia de los ladrillos de arcilla triturados y del agente curador interno, asi como tambien la necesidad de realizar investigacion mas profunda en la utilizacion del agregado ligero evaluado como agregado de curado interno en el concreto. La investigacion prueba que La mamposteria de arcilla triturada cumple el comportamiento esperado en un agente de curado interno desde el punto de vista de durabilidad y resistencia, mientras que el agregado ligero evaluado produjo una reduccion en la resistencia y la durabilidad del concreto. El comportamiento observado en cuestion de resistencia y durabilidad es especialmente cambiante para la edad de 180 dias, en comparacion con los concretos convencionales.

Palabras clave: Absorcion, Agregados ligeros, Asentamiento, Concreto ligero, Contraccion, Curado interno, Polimeros superabsorbentes SAP, Resistencia a cloruros.

Introduction

The ACI 308-213 R-13 defines curing of concrete as the process through which the concrete matures and develops its hardening properties over time as a result of the continuous hydration of the cement in the presence of enough water and heat amount (ACI, 2013).

For years, the most widely used curing method has been external curing. It consists in the superficial application of water to the concrete, through a constant exposition at the surface by means of periodic irrigation of water or with the use of materials with good absorption and desorption capacities, such as sawdust and some polymers. In some cases, the elements are completely immersed in a pool of water, as in the case of test specimens and precast elements.

However, in the daily practice, immersing cast structural elements in situ is not an option. In these cases, the periodic application of water or the use of some external agent in order to conserve the moisture are implemented, as is shown in Figure 1.

[1] Civil Engineer, Escuela Colombiana de Ingeniería Julio Garavito, Colombia. M.Sc. in Civil Engineering, Escuela Colombiana de Ingeniería Julio Garavito, Colombia. Affiliation: Structural Engineer, Jäger Engenieuren GmbH, Germany. E-mail: sdrtorres@gmail.com
[2] Civil Engineer, Universidad Francisco de Paula Santander, Colombia. Ph.D. in Materials Science and Technology, Universidad Nacional de Colombia, Colombia. Affiliation: Associate Professor, Escuela Colombiana de Ingeniería Julio Garavito, Colombia. E-mail: nancy.torres@escuelaing.edu.co

Figure 1. Concrete external curing.
Source: http://blog.360gradosenconcreto.com/

According to Neville (2010), the main problem that could occur during the external curing is call slow-flow. This effect takes place when the curing water starts circulating into the concrete and the external curing water is evaporated from the concrete. This makes that only the surface of the element and a small internal layer of little thickness and to the surface are cured and not the whole volume of the element, as expected. That is why the thicker the piece is, the higher the volume of uncured concrete will be. Therefore, in order to ensure an efficient surface curing, a permanent sheet of water must be guaranteed on the concrete surface for a long time. This condition is difficult to ensure on large surfaces, in isolated places, in hot climates and in places with water supply problems. Additionally, the lack of awareness in the construction area about the importance of an efficient external curing for the adequate behavior of the concrete makes this process hard to control.

Additionally, the ACI 308R-01 defines internal curing (IC) as the "process where the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water" (ACI, 2008). According to the Expanded Shale, Clay and Slate Institute (ESCSI), internal curing helps concrete to develop its full potential in a simple, economical and sustainable way. The IC improves hydration, reduces early cracking, reduces chloride penetration and improves durability, all of which extend the service life of the concrete.

In Figure 2, the comparison between the surface curing and the internal curing shows that the former works as a hard shell around concrete elements, while the latter makes uniform hydration of the concrete. Both, superficial and internal, could ensure homogeneous curing within the concrete mass.
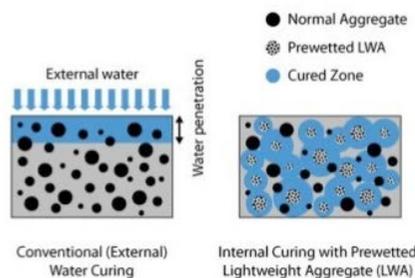

Figure 2. Internal and external curing comparison.
Source: ESCSI

According to this, a new paradigm has arisen in response to the deficient external curing practices used in infrastructure works and, especially, facing the difficulty of curing concrete with low w/c ratio. This paradigm is called internal curing of concrete and consists in storing water inside the concrete that is not available during the mixing or in the first hydration stages but is released later for curing. In order to achieve this behavior, saturated lightweight aggregates are used, since they can provide curing water from within the mixture thanks to their absorption and desorption properties.

In Colombia, according to the technical bulletin from March 15th, 2016 issued by the DANE, the use of concrete as construction material amounts to 8 500 m^3, which places it as the most widely used construction material in the country. Road infrastructure, warehouse floor slabs, concrete walls, columns and beams are, among others, the civil works with most problems in service and maintenance. The main reason is the lack of curing in the early ages of concrete, which is when the properties of strength and durability that the concrete will have during its service life are developed.

The Colombian Seismic Resistant Code (NSR-10), in its title C, defines lightweight concrete as concrete with lightweight aggregate, that has an equilibrium density between 1 440 and 1 840 kg/m^3 (AIS, 2010), as defined also by the NTC 4022 (ICONTEC, 1994) based on the ASTM C567. Likewise, the Colombian technical standard NTC 4045 provides the characteristics that a lightweight aggregate must fulfill to be part of structural concrete (ICONTEC, 1997), based on the American specification ASTM C641.

Notwithstanding the inclusion of lightweight concrete within national regulations, the use and commercialization of the lightweight aggregate for concrete are limited due to the lack of research that supports its operation, not regarding lightweight concrete but also in the practical field as internal curing agents. Possible use of lightweight aggregates nationwide could take place when a high volume of concrete is used, and it is difficult to ensure a continuous and prolonged supply of water. The use of lightweight aggregates as internal curing aggregate of concrete could be a good alternative to avoid the current wrong practices in the curing stage and as a solution to develop infrastructure in the regions where it is not possible to ensure continuous water supply.

Before using the lightweight aggregates available in the national context as internal curing agents, it is necessary to evaluate their behavior through a partial incorporation into concrete that allow the characterization of their properties in fresh state, its mechanical strength, and the influence on the durability. Subsequently, this also allows the formulation of concrete dosages with lower density than in conventional concrete with the aim to achieve similar properties.

In order to evaluate the benefits of the lightweight aggregate as an internal curing agent, an experimental program was performed. Specimens with a different concrete matrix were tested using two types of lightweight aggregates. Each one was included in the concrete matrix instead of a percentage of the normal weight coarse aggregate. The first lightweight aggregate was calcined clay and the second one was recycled

crushed clay bricks (CCB) in the laboratory. An internal curing agent, commercially known as "Better Mix" and supplied by the company Toxement, was also evaluated.

The effects of internal curing were tested in six different concrete mixtures. The first mixture (M1) was a control sample, while the second (M2) and third mixtures (M3) had an addition of calcined clay with a partial replacement of the coarse aggregate in percentages of 15 % and 20 %, respectively. Likewise, the fourth (M4) and fifth (M5) mixtures contained the same percentage of replacement of the coarse aggregate, but the substitution material was the CCB aggregate. Finally, the performance of the Better Mix curing agent was assessed in the sixth mixture (M6).

Materials and Testing Procedure

Materials

The CCB aggregate was obtained from crushing 11-inch clay blocks, obtained from the external service tests of the Structures Laboratory of the Escuela Colombiana de Ingeniería Julio Garavito, as shown in Figure 3. The selection and characterization tests were carried out according to the standards presented in Table 1.

Figure 3. Crushed clay bricks aggregate.
Source: Authors

Table 1. Physical properties of aggregates

TEST	NTC	ASTM
Sieve analysis of aggregate	4045	C330
Determination of density and absorption	176	C127
Determination of unit mass and voids	92	C29

Source: Authors

The characterization of the second lightweight aggregate was carried out in the Soil and Geotechnics Laboratory of Escuela Colombiana de Ingeniería Julio Garavito, following the same characterization standards stipulated in Table 1.

The third internal curing agent was the commercially known "Better Mix" supplied by Toxement, which is a concrete additive that has the property of holding water.

Due to the used w/c ratio (w/c = 0,30), it was necessary to use a Superplasticizer additive. The additive used was "Eucon MR 500", supplied by Toxement. The dosage was calculated

according to the recommendations of the manufacturer (1,5 % of cement weight).

Characterization of the materials

Results of the characterization tests of the aggregates are shown in Table 2.

Table 2. Physical properties of the aggregates

Aggregate	Ds_{bulk}	$Ds_{apparent}$ (sss):	$D_{nominal}$	Absorption
	kg/m^3	kg/m^3	kg/m^3	(%)
CCB	1 807	2 012	2 275	11,37
Calcined clay	410	870	840	29,50
Gravel	1 530	2 660	2 620	1,60

Source: Authors

Mixture design

For the design of the mixtures, the recommendations of the ACI 211.1 were followed (ACI, 1991). In common practice, the internal curing was used to obtain high strength concrete, therefore, a low w/c ratio of 0,30 was chosen.

The amount of cement and the amount of water for all the mixtures was kept fixed and partial replacements of coarse aggregate were made by the two lightweight aggregates previously described. For these replacements, the average density between the stone aggregate and the lightweight aggregate was calculated, in order to find the necessary quantities of each one. For each of the mixtures evaluated, the lightweight aggregates were pre-moistened for 24 hours prior to the preparation of the mixture. Due to this pre-moistened, the incorporated water was discounted from the calculated mix of water.

The cement used in this research was supplied by the Argos Company and characterized through the X-ray fluorescence test, in the laboratories of the Universidad Nacional de Colombia. The characterization was done in a solid cement sample in order to obtain its chemical composition, density and fineness. The characterization of the cement is presented in Table 3.

Table 3. Physical and chemical properties of the cement

Element or Compound	%
CaO	61,015
SiO_2	20,906
SO_3	5,868
Al_2O_3	4,783
Fe_2O_3	3,632
K_2O	1,047
Cement density (gr/cm^3):	3,070
Fineness S(cm^2/gr):	4 213

Source: Authors

Table 4 shows the dosage of the 6 mixtures evaluated and the dosage per m^3 of concrete.

Table 4. Dosage per m^3

Mix	Water (kg)	Cement (kg)	Sand	Coarse	Lightweight Ag.	
					CCB	Clay Calc.
M1	178,0	668	790	716		
M2	194,0	668	835	822		207,3
M3	187,0	668	817	795		107,6
M4	168,6	668	815	582	172,0	
M5	158,8	668	815	640	100,2	
M6	163,6	668	804	717		

Source: Authors

Test specimens

For the development of this research, three different types of specimens were used. Specimens type 1 were 12 slabs of 350 x 250 x 200 mm, whose dimensions were determined in order to extract 6 standard cylinders of 100 mm diameter and 200 mm high from each specimen, by means of a core extraction drill. The extraction set can be observed in Figure 4.

Figure 4. Concrete core extractions.
Source: Authors

Concrete slabs were used instead of standard cylinders based on the recommendations given in the State-of-the-Art report of RILEM 196-ICC (Klover and Jensen, 2007). The authors suggest that it is necessary to have specimens with greater area and volume than the conventional cylinders, in order to evaluate the internal curing effects. The casting process of this type of specimens consisted in placing two layers of fresh concrete, each one was tamped 20 times with a smooth steel bar of 16 mm in diameter and 600 mm in length. Then, the molds were externally compacted with a rubber mallet in order to diminish the anthills. Subsequently, the edges and the remaining material were leveled.

The compression, modulus of elasticity, ISAT, chlorides and sorptivity tests were performed on the 100 x 200 mm cores extracted from specimens type 1, according to the corresponding ASTM standards. The tests were performed

after 28 and 180 days, in order to obtain a representative estimation of the concrete performance at two different ages. 12 specimens were analyzed per mixture at each test date, for a total of 144 cylinders.

In order to evaluate the performance of the concretes, it was necessary to make twin specimens of each mixture. Half of these were preserved in submerged state and the other half were conserved in a room with controlled temperature and humidity at 55 %, and constant temperature of 25 °C. These conditions were hold until the core extraction and test age.

In Figure 5, some specimens type 1 are shown, after the extraction of the cylinders.

**Figure 5.** Specimens type 1.
Source: Authors

Specimens type 2 were prisms with dimensions 150 x 150 x 50 mm and elaborated following the parameters established in the NTC 3494, in order to evaluate the loss of water of the concrete and the influence of the internal curing. The specimens were preserved as specimens type 1: three per each mixture in the controlled-temperature room and three in submerged conditions until the day of the test.

Specimens type 2 were elaborated following the same process described above for specimens type 1.

Finally, specimens type 3 were standard prismatic of 75 x 75 x 250 mm, made for the volumetric variation test, according to the ASTM C157. Six specimens were made from each mixture. three of them were submerged and three were storaged in a room with controlled temperature and humidity, as well as the other specimens. A total of 36 specimens were made.

Nomenclature

For the identification of the different specimens, the nomenclature from Figure 6 was used.
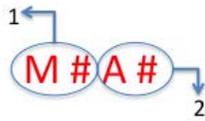
1: Refers to the mixture, M1, M2, M3... M6

2: refers to the curing environment used, A means that it was preserved in the submerged state

Figure 6. Nomenclature.
Source: Authors

Results and discussion

Properties of fresh concrete

Shows the fresh-state properties recorded for the different mixtures.

Table 5. Properties of fresh concrete

Mixture	Slump(mm)	Air content(%)	Unitary mass (kg/m^3)
M1	25	2,0	2 281
M2	60	2,5	2 029
M3	55	2,0	2 123
M4	85	3,0	2 262
M5	95	3,0	2 205
M6	53	2,5	2 252

Source: Authors

As observed in Table 5, the unit mass decreased from Mixture 2 to Mixture 6 in around 1 % and 12 %, compared with Mixture 1. This is due to the lower density of the lightweight aggregates used in the mixes compared with the standard one. In large volumes of concrete, this would represent a considerable weight reduction. However, our mixes could not be considered lightweight concrete according to the definition given before. The air content has not appreciable alteration due to the use of lightweight aggregates.

The lightweight aggregates improved the manageability between 2,2 and 3,8 times compared with the standard sample. It changed from a slump of 25 mm for the standard sample to a range between 55 and 95 mm. This could be attributed to the fact that the mixing water is not absorbed by the aggregates, because these were previously saturated, thus allowing a uniform distribution of water in the mixture. This increase in the manageability for high strength concrete with low w/c ratios represents an advantage for its handling.

Mechanical properties

Compressive strength: Figure 7 shows the compressive strength for the samples cured in the controlled temperature room. Figure 8 shows the compressive strength for the pool-cured samples. Both graphics show the results of the average compression strength of the three specimens in the aforementioned test ages.

An increase of the strength resistance from the 28 days to the 180 days was observed in the standard mixture (M1) as well
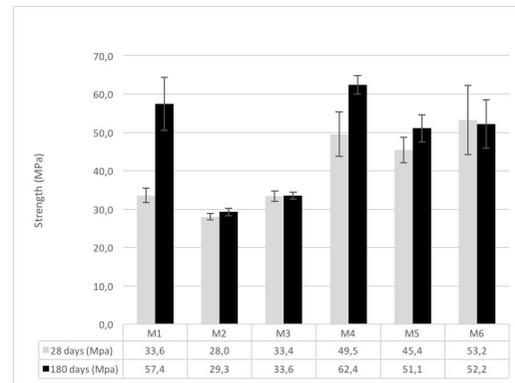

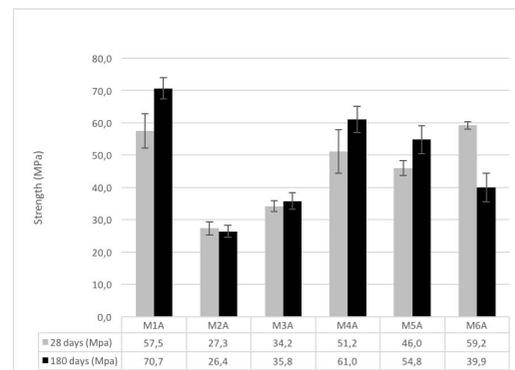**Figure 7.** Compressive strength, samples in controlled temperature and humidity room.
Source: Authors

Figure 8. Compressive strength, submerged samples.
Source: Authors

as in the mixes with CCB aggregate (M4, M5), between 26 % to 70 %, suggesting an increase of the strength at long ages. Mixes with the calcined clay presented just a slight variation smaller at the 4 %, which induced the maximal strength resistance in these mixes within 28 days. The mixture with the superplasticizer (M6) presented a bigger reduction in the strength resistance for the submerged samples, however, it is necessary to increase the number of specimens in this mixture before concluding this behavior. Among all the specimens, the maximal strength at 180 days was for the Mixture 1 in submerged state, as expected, with 71 MPa. The closest strength to this maximal value was observed in the Mixture M4 in the controlled temperature room, only with a reduction of the 11,7 %, which suggests the effectiveness of the internal curing. Additionally, comparing this mixture in submerged and non-submerged state did not show a representative variation in the strength, which then allows to infer that the internal curing in this mixture is optimum.

Meanwhile the standard mixture M1 has a strength reduction of almost 20 % between the specimens submerged and non-submerged. The specimens cured internally have just a difference between 3 % and 10 %, therefore it could be said that the internal curing really occurred, and that its success depends on the dosage and kind of the aggregate.

Figure 9 shows the percentage difference between the resistance obtained in the standard mixture in the submerged state and the mixtures conserved in the room with controlled humidity and temperature.
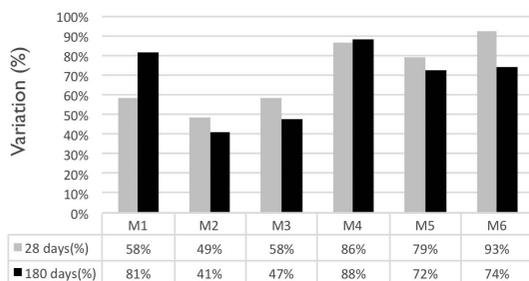

Figure 9. Variation of the compressive strength in mixtures conserved in the room compared with the standard mixture in submerged state after 28 and 180 days.
Source: Authors

It is observed that the samples with crushed clay bricks (M2 and M3) achieved a compression resistance equivalent to 88 % of the externally cured standard mixture after 180 days. In addition, M2 and M3 presented a similar strength in the cylinders conserved in the room with controlled humidity and temperature to those preserved in the submerged state, thus proving the properties of crushed clay bricks as curating agent.

The mixes with calcined clay, M2 and M3, obtained the greatest reduction in compressive strength. The internally cured samples achieved only 41 % of the resistance achieved by the standard sample.

From the foregoing, it could be observed that the compressive strength of mixtures with lightweight aggregates depended fundamentally on two factors: the percentage of coarse aggregate substituted by lightweight aggregate and the type of lightweight aggregate used. Comparing the behavior obtained for the concretes with lightweight aggregate of calcined clay against concrete with CCB aggregate in equal replacement percentages, a variation of the resistance is observed up to 49 %, where the CCB mixes obtained the higher strength. In addition, all mixtures with lightweight aggregates, the ones in the room as well as the ones in the submerged state, had lower compressive strength than the standard mix. This result agrees with the conclusions of Shafigh, Jumaat, Mahmud and Hamid (2012) regarding the reduction of resistance in mixtures with lightweight aggregates.

Modulus of elasticity: The procedure followed to evaluate this property was as specified in the ASTM C469 standard (2014). Figure 10 shows the average moduli of elasticity for the samples preserved in the room with controlled humidity and temperature.

Figure 11 shows the average modulus of elasticity for the samples in submerged state. It shows that the standard mixture obtained the largest modulus of elasticity (27 375 MPa), after 180 days. The modulus of the mixture with the curative agent preserved in the room with controlled humidity

and temperature was the closest to the standard sample after 180 days (25 565 MPa), while the sample with the lowest elasticity modulus corresponded to the mixture with 15 % replacement of the coarse aggregate with calcined clay after 180 days (19 889 MPa).
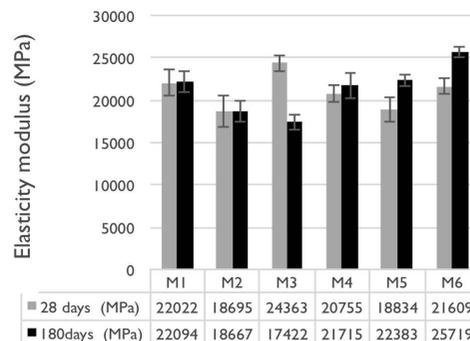

Figure 10. Moduli of elasticity, samples preserved in the room.
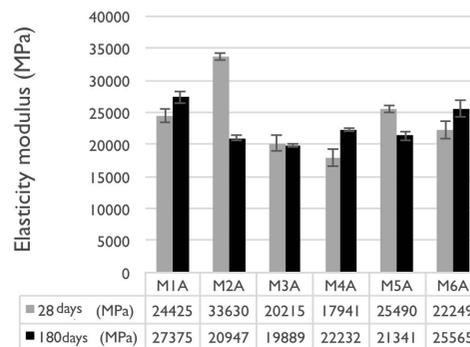**Source:** Authors

Figure 11. Modulus of elasticity, samples in submerged state.
Source: Authors

The variation of the elasticity modulus was different for all mixtures. In the case of the standard mixture in submerged state, and the samples with 25 %, replacement of the coarse aggregate by CCB in the room (M4), there was no variation in the modulus of elasticity after 180 days regarding the modulus obtained after 28 days. Meanwhile, all the other samples showed a variation between 10 % and 40 %, which is attributed to the difference in the composition of each mixture.

The only mixture with a decreasing modulus of elasticity was mixture M3 with a decrease of 29 %, which suggests the need of additional tests to determine the reason for this decrease.

Figure 12 and Figure 13 show the relation between the compressive strength and the modulus of elasticity, according to the following equation:

$$E = K\sqrt{f'c} \qquad (1)$$

As observed in the figures, the relation constant between the modulus of elasticity and the $f'c$ is different for every mixture and curing environment. The M2A had a K value

of 4 080, whereas the other mixtures had a *K* value lower than 3 500. Compared with the values defined by the NSR-10 for concretes with a unit mass between 1 440 and 2 460 kg/m³, the closer constant corresponds to the one defined for sedimentary aggregates with a *K* value of 3 600 (AIS, 2010).
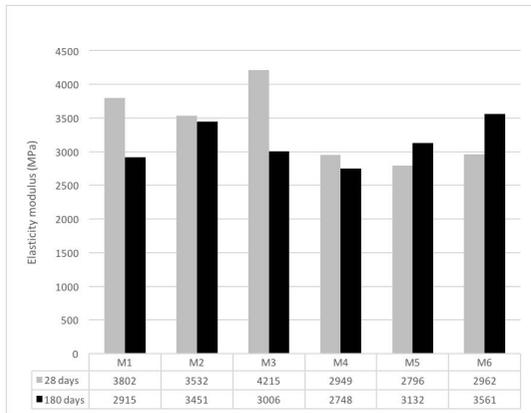

Figure 12. Relation of the modulus of elasticity and the $f'c$ in the samples preserved in the room.
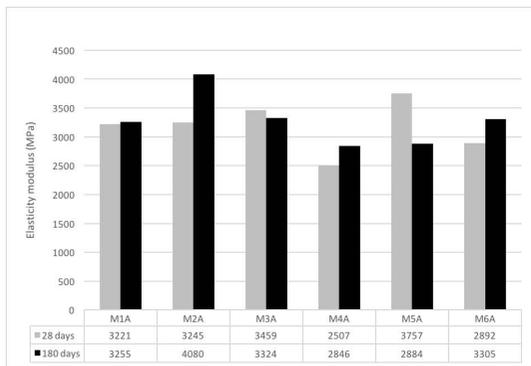**Source:** Authors

Figure 13. Relation of the modulus of elasticity and the $f'c$ in the samples preserved in submerged state.
Source: Authors

Durability properties of the concrete compressive strength

ISAT – Initial surface absorption test: this test was carried out following the guidelines described in the English standard BS-1881 part 5: Testing concrete.

For the ISAT, data were taken after 10, 30 and 60 minutes per sample, according to the aforementioned standard. Results are presented after 10 minutes, because the trend observed at that time was constant for the rest of the measurement. However, for the following reading time values, the absorption values were lower due to the corresponding pore saturation.

Figure 14 and Figure 15 show the results obtained from water absorption for each of the concrete samples, measured at 10 minutes.
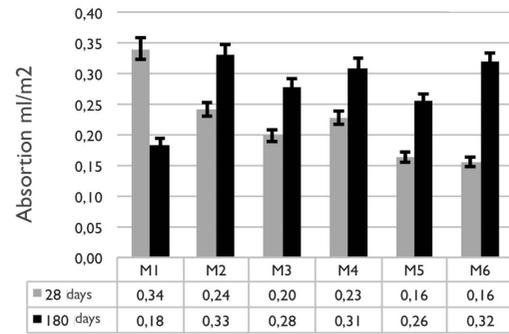

Figure 14. ISAT after 10 minutes for samples preserved in the room.
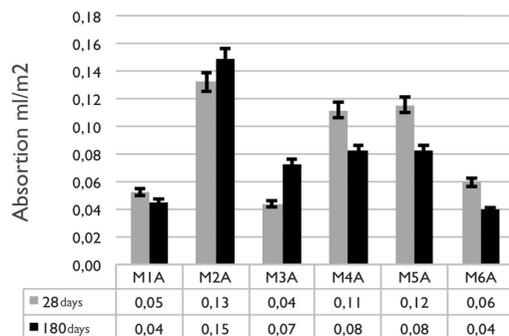**Source:** Authors

Figure 15. ISAT after 10 minutes for samples preserved in submerged state.
Source: Authors

Mixtures with light internal curing aggregates had an increase in the initial water absorption rate between 26 % and 36 % after 180 days. This can be attributed to the porous nature of the lightweight aggregates. The samples of the standard specimen preserved in the room with controlled humidity and temperature achieved an absorption decrease of 84 %.

It is concluded that concretes with lightweight aggregates obtained a greater absorption than the externally cured standard sample, which confirms the conclusions made by Castro, Keiser, Golias and Weiss (2011). However, it is worth clarifying that external curing was performed under ideal laboratory conditions where the samples were saturated until the day of the test and that those conditions are not reproducible in practical cases.

Chloride penetration: this test, as defined by the ASTM C1202-12 standard (2012), allows the determination of the electrical conductivity of the concrete to provide a quick indication of its resistance to chloride ion penetration. Figure 16 and Figure 17 show the current flowing through the test specimens for each of the mixtures after 28 and 180 days. In summary, a lower penetration of chlorides was obtained in the mixtures conserved in the room, which achieved a reduction of 34 % after 180 days, regarding the penetration obtained after 28 days.
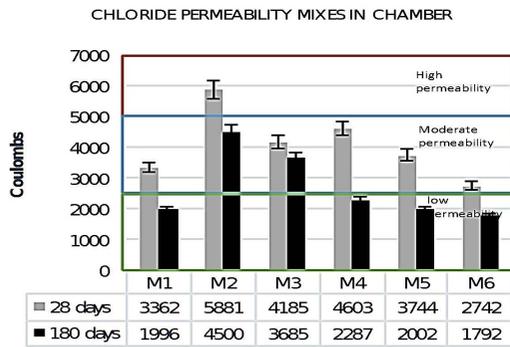
CHLORIDE PERMEABILITY MIXES IN CHAMBER

	M1	M2	M3	M4	M5	M6
28 days	3362	5881	4185	4603	3744	2742
180 days	1996	4500	3685	2287	2002	1792

Figure 16. Permeability of chloride ions in samples preserved in the room.
Source: Authors

CHLORIDE PERMEABILITY MIXES SUMERGED STATE

	M 1A	M 2A	M 4A	M 3A	M 5A	M 6A
28 days	5123	5938	6206	4603	5154	4471
180 days	2745	3823	2811	2287	3006	2234
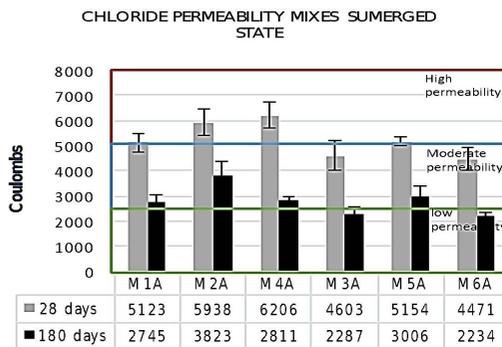
Figure 17. Permeability of chloride ions in samples preserved in submerged state.
Source: Authors

Samples with internally cured calcined clay recorded a greater passage of Coulombs ranging from 34 % to 64 % at 180 days compared with the mixture preserved in the room. The mixtures with CCB registered a reduction in the passage of Coulombs between 17 % and 27 % after 180 days, compared with the sample preserved in the camera. The mixture with the curing agent recorded the smallest Coulombs passage among all the samples evaluated and it had a 35 % lower step at 180 days than the externally cured standard sample.

Except for the internally cured sample 2 (M2), all the mixtures recorded a moderate and low passage, thus indicating an acceptable chloride migration. At the age of 180 days, a transcendental reduction occurred in the passage of Coulombs, changing the categorization of moderate to low in all the evaluated mixtures, which agrees with what was found by Dayalan and Buellah (2014).

Microscopy: the main objective of this test was to observe the interaction between the aggregates and the cement paste within the concrete matrix. The microscopy test was performed in mixtures M3 and M6.

In Figure 18 and Figure 19, the interaction between the aggregate and the cement paste can be observed. There is a noticeable change of tone between the cement paste and the lightweight aggregate. It can be concluded that the darkest shade is the superficial part of the lightweight aggregate and the clear part corresponds to the cement paste, where there

are signs of perimeter humidity, which indicates the expulsion of the internal curing water.
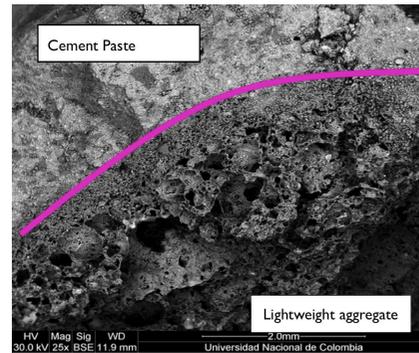

Figure 18. Microscopy of mixture M3 (25x).
Source: Authors

Figure 19, which belongs to sample 6, shows small elongated spots distributed around the entire cement paste, which correspond to the curing compound from Toxement.
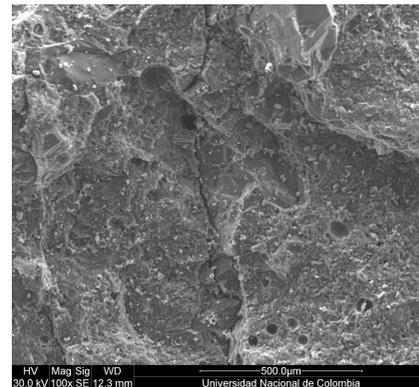

Figure 19. Microscopy of M6 (50x).
Source: Authors

Conclusions

The crushed clay bricks in partial replacement of 25 % of coarse aggregate, presented the best behavior in the different tests carried out and surpassed the sustainability point of view. This can represent a benefit, given that waste of the clay units is generated in buildings, due to its fragility, and it can become an economic option when used as a lightweight aggregate for the internal curing of the concrete; thus, decreasing the environmental impact. Nevertheless, the optimal replacement percentage should be proved for each concrete mix, through probe mixes.

Calcined clay does not have good behavior in the tested conditions, the mechanical and durability characteristics were always reduced compared with the standard mix. The authors suggest additional research with different densifications and different aggregate granulometry in order to obtain further conclusions.

In all the internally cured mixtures, there was a reduction in the strength resistance. This is contrary to the conclusion given by Saffar, Saad and Tayeh (2019), where the authors state that the internal curing should increase the strength resistance. However, their conclusion is based on experimentation with fine aggregates.

The Better Mix curing agent had a good behavior in all the tests evaluated, but also had a reduction in the strength of 32 % in submerged conditions. This suggests a limitation in its use for external members. It is also recommended further research with different humidity conditions.

Acknowledgements

References

ACI Committee 211 (1991). *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete* (ACI 211.1-91). Farmington Hills, MI: American Concrete Institute.

ACI Committee 308 (2008). *Guide to Curing Concrete* (ACI 308 R-01). Farmington Hills, MI: American Concrete Institute.

ACI Committee 308-213 (2013). *Report on Internally Cured Concrete Using Prewetted Absorptive Lightweight Aggregate* (ACI 308-213 R-13). Farmington Hills, MI: American Concrete Institute.

AIS (2010). *Reglamento colombiano de construcción sismo resistente* (NSR-10). Bogotá: Asociación Colombiana de Ingeniería Sísmica,

ASTM C157/C157M-17 (2017). *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*. West Conshohocken, PA: ASTM International. DOI: 10.1520/C0157_C0157M-17

ASTM C1585-13 (2013). *Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes*. West Conshohocken, PA: ASTM International. DOI: 10.1520/C1585-13

ASTM C1202 (2012). *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*. West Conshohocken, PA: ASTM International. DOI: 10.1520/C1202-19

ASTM C469/C469M (2014). *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*. West Conshohocken, PA: ASTM International. DOI: 10.1520/C0469

Bentz, D. P., and Weiss, W. J. (2011). *Internal Curing: A 2010 State-of-the-Art Review* (NIST Interagency/Internal Report (NISTIR) – 7765). DOI: 10.6028/ NIST.IR.7765

Castro, J., Keiser, L., Golias, M., and Weiss, J. (2011). Absorption and desorption properties of fine lightweight aggregate for application to internally cured concrete mixtures. *Cement and Concrete Composites*, *33*(10), 1001-1008. DOI: 10.1016/j.cemconcomp.2011.07.006

Dayalan, J., and Buellah, M. (2014). Internal Curing of Concrete Using Prewetted Light Weight Aggregates. *International Journal of Innovative Research in Science, Engineering and Technology*, *3*(3), 10554-10560. Retrieved from: http://www.ijirset.com/upload/2014/march/95_Internal.pdf

ICONTEC. (1994). *NTC 4022 – Masa unitaria de concreto liviano estructural*. Bogotá: ICONTEC.

ICONTEC. (1997). *NTC 4045 – Agregados livianos para concreto estructural*. Bogotá: ICONTEC.

ICONTEC. (2005). *NTC 3494 – Determinación de la retención de agua de los materiales utilizados para el curado del concreto*, NTC. Bogotá: ICONTEC.

Kovler, K. and Jensen, M.O. (Eds.). (2007) *Internal Curing of Concrete - State-of-the-Art Report of RILEM Technical Committee 196-ICC*. Bagneux: RILEM publications.

Neville, A. M. M., and Brooks, J. J. (2010). *Concrete Technology*. Harlow, England, New York: Prentice Hall. DOI: 10.1016/ 0360-1323(76)90009-3

Shafigh, P., Jumaat, M. Z., Mahmud, H. Bin, and Hamid, N. A. A. (2012). *Lightweight concrete made from crushed oil palm shell:* Tensile strength and effect of initial curing on compressive strength. *Construction and Building Materials*, *27*(1),252-258. DOI: 10.1016/ j.conbuildmat.2011.07.051

Saffar, D. M. Al, Saad, A. J. K. Al, and Tayeh, B. A. (2019). Effect of internal curing on behavior of high-performance concrete: An overview. *Case Studies in Construction Materials*, 10(e00229). DOI: 10.1016/j.cscm.2019.e00229