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COMPARISON OF MASONRY CURING SYSTEMS

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ABSTRACT

Given the current complementary requirements for structural masonry and the growth of the industry in Costa Rica, the need has arisen to implement production processes that allow to obtain improvements in the resistance to the compression of concrete blocks without the necessity of incurring in large economic changes. As a result of this, the task of analyzing the effect of curing in concrete blocks with dry mixtures has been given by the experimental proposal of 13 methods of curing in the laboratory, by testing a batch of 5 blocks to 24 hours, 8 and 28 days. From the implemented systems, a comparison was made between pieces without any cure and others exposed to a method assigned as the "ideal". The proposed systems were determined considering the weather, the manufacture site characteristics, economic feasibility, place and accessibility to the materials. Finally, a comparative table of the methods with greater projection and practicality in its application at industrial level, is made. With the results obtained, it is possible to determine the importance of cure at early ages in concrete blocks with dry mixtures, including the methods of ease application at industrial level, considering the percentage in strength increase due to the correct application in the curing times.

KEYWORDS: *curing, concrete block, masonry, methods, dry mix, proposals*

INTRODUCTION

The manufacture of existing concrete blocks and the need of develop production systems with greater benefits without the need to incur in large economic investments has led the task of studying the factors of greatest incidence in the final resistance of concrete blocks. Since concrete blocks are made up of dry mixtures, their low plasticity and low settling do not allow a good adhesion between their physical components, much less a good workability, as in the case of more plastic concretes. As a consequence, a suitable compaction percentage is required for the mixture

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to present the physical bonding of the aggregates and a homogeneous behavior. Concretes with a high cement content and a water/cement ratio below 0.40 require special curing processes. As the cement hydrates, the relative humidity of the mixture is reduced, causing the paste to lose a significant percentage in its moisture content if no water is supplied by an external medium. This loss of moisture in the paste can alter the final desired properties of the concrete, especially if it falls below 80% in the first 7 days. Under these conditions the curing membranes can not retain the amount of water needed in the concrete, in this case the use of additional water curing or fogging used by and after the placement of the concrete is recommended, a process that benefits the reduction of cracks by contraction in concretes with a water/cement ratio around 0.3 [5].

Compared with the curing of other cement elements, curing of the blocks is especially delicate due to the extreme conditions from which these components are dosed. When using minimum amounts of water and cement in the manufacture of blocks, this requires the constant presence of water in order to ensure that the reactions of the existing cement in the mixture are produced completely. The most commonly used curing systems for the production of concrete blocks are natural curing or steam curing.

In order to evaluate the importance of curing on dry mixes and the selection of an ideal method at the industrial production level, thirteen methods of curing in the laboratory were prepared, which allowed to analyze the resistance to early ages and their impact on the development of the blocks.

This study allowed us to determine the percentage effect of curing in dry mixes by means of the proposal and comparison of thirteen methods of curing applied in the laboratory, highlighting an optimum system for application at industrial level vs. one without any cure.

EXPERIMENTAL TEST PROPOSAL

The curing process fulfills 3 functions depending on its application method, retain the water in the concrete mixture during the early hardening process, reducing the water loss of the concrete surface mixture, and accelerating the gain of the compressive strength using additional heat and moisture. Although heat by steam is one of the most used methods for curing block production, it is a process that has been left out because of its high cost in application, in addition to being a method that promotes the gain of resistances at early ages and a slight reduction at 28 days.

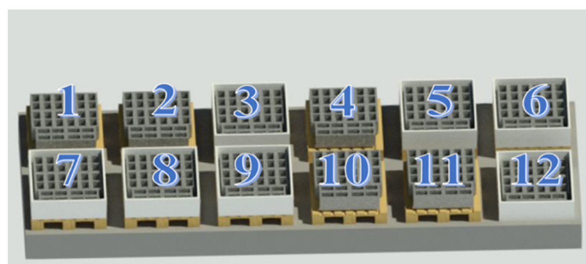
After analyzing the three functionalities, a series of curing alternatives are proposed based on the requirements of the dry mixes, as we know, the concrete blocks have a minimum moisture content in their mixture, and to analyze methods of cure that involve The incorporation of water through external agents, was indispensable. Based on the proposed methods, the logistics of extraction of the curing chambers were carried out without affecting the integrity of the blocks, providing a reasonable time, in which the samples had the necessary consistency to be removed to the test areas.

Due to the difficulties of extracting the blocks from the curing chambers once they have been demolded, the application of the methods in laboratory presents an approximate loss of 5 to 6 hours

(21-25%) in the cure at early ages (24 hours), primarily taking into account the initial four hours of rest and setting of the concrete, as well as placement in each of the respective areas of the method, fundamental lapse in dry mixtures to avoid the loss of moisture of the blocks necessary for the hydration process. In order to perform the analysis, 5 blocks of concrete were extracted from the curing chambers for the compression test at 24 hours, 8 and 28 days, which equals a total of 195 units in the 13 methods. It is important to take into consideration that all the blocks had a density of approximately 2110 km/m^3, and consider a net area of 260 cm^2. For their test at 8 and 28 days, the capping process was performed according to the INTE 06-02-16 [3] standard, meanwhile, for the test at 24 horas, the imperfections and rough areas were removed with a paddle or blade.

Figure 1(a) shows the different methods proposed *in site*, followed by Figure 1(b) which has the initial (suggested) scheme of placement of the different proposals. As can be observed, there is a variability in their locations, this is due to the fact that the wet chambers were placed as a micro sprinkler serial system, in which we could ensure that the water flow in a single existing enclosure could be decreased being distributed among several curing chambers. In addition, the spray systems were placed in one area and the covers in another, trying to avoid the direct contact of the water from one method to another.

(a)



(b)

Figure 1: (a) On-site methods, (b) Initial proposed methods sketch

Where:

1. Non-curing outdoor concrete blocks for 28 days (NCO).
2. Non-curing indoor concrete blocks for 28 days (NCI).
3. Concrete blocks cured in moist chamber simulation * for 28 days (MC).
4. Concrete blocks cured with sprinklers for 7 days, followed by 21 days outdoors with no curing processes (S+NCO).
5. Concrete blocks cured in moist chamber simulation * for 24 hours, followed by 27 days of outdoor water sprinklers (MC+S).

6. Concrete blocks cured in moist chamber simulation * for 24 hours, followed by 6 days of outdoor water sprinklers and finally 21 days outdoors with no curing processes (MC+S+NCO).
7. Concrete blocks cured in moist chamber simulation * for 24 hours, followed by 6 days of cure using saturated coverings (burlap according AASHTO M182) with a polyethylene film on top, and finally 21 days outdoors with no curing process (MC+SC+NCO).
8. Concrete blocks cured in moist chamber simulation * for 24 hours, followed by 6 days of cure using saturated coverings (burlap according AASHTO M182) with a polyethylene film on top, and finally 21 days of outdoor water sprinklers (MC+SC+S).
9. Concrete blocks cured in moist chamber simulation * for 24 hours, followed by 27 days of curing by saturated coverings (burlap according AASHTO M182) with a polyethylene sheet on top (MC+SC).
10. Concrete blocks cured with saturated coverings with a polyethylene film on top for 7 days, followed by 21 days outdoors with no curing process (SC+NCO).
11. Concrete blocks cured with saturated coverings with a polyethylene film on top for 28 days (SC).
12. Concrete blocks cured with a Prodex ** thermal insulation cover for 28 days (P).
13. Concrete blocks cured in a polystyrene foam case with a sheet of water in the bottom of the box for 28 days (PWB).

* Polystyrene case with the ability to retain the temperature (21-25 ˚C) and relative humidity (greater than 95%). Fogging applied.

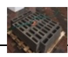
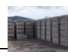
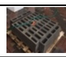
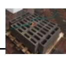
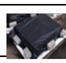
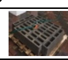
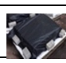
** Thermal insulation produced in Costa Rica used in roofs

BLOCK TEST ACCORDING TO ASTM C140 / C140M - 14B STANDARD

From the test of the blocks, an average of the 5 resistances achieved in each of the different ages was realized, including a more accurate result of the sampling that the INTE 06-02-13 [2] demands with 3 blocks. In order to have a better perspective of the acquired results, a summary table is made that contains the 13 methods with their average resistance, respective curing period, amplitude, minimum and maximum strengths with their respective graph.

As can be seen, the methods with more relevant results, are those which includes additional water at the 24 initial horas, inclusive the saturated coverings brings sensitive gains in the blocks resistance, however, the saturated burlap and Prodex cover, imply a difficult placement process, as well as the reuse of the material.

Table 1 Summary fc of blocks exposed to different times and methods of cure

Summary fc of blocks exposed to different times and methods of cure.										
Method	Cure (days)	fc (days).	fc, Kg/cm2 (MPa)		Max. fc, Kg/cm2 (MPa)		Min. fc, Kg/cm2 (MPa)		Amplitude, Kg/cm2	Standard Deviation
1. NCO	1	1	52.1	(5.1)	56.3	(5.5)	45.8	(4.5)	10.5	4.10
	7	8	102.3	(10.0)	107.9	(10.6)	96.8	(9.5)	11.2	4.24
	25	28 (f'c)	144	(14.1)	150.4	(14.8)	135.1	(13.3)	15.3	7.46
2. NCI	1	1	54	(5.3)	58.6	(5.7)	51.4	(5.0)	7.2	2.85
	7	8	111	(10.9)	117.7	(11.6)	102	(10.0)	15.8	6.17
	25	28 (f'c)	128.8	(12.6)	138.0	(13.5)	115.6	(11.3)	22.4	10.45
3. MC	1	1	61.9	(6.1)	63.8	(6.3)	59.4	(5.8)	4.4	1.91
	7	8	134.2	(13.2)	144.4	(14.2)	127.9	(12.5)	16.5	6.71
	25	28 (f'c)	176.6	(17.3)	191.2	(18.8)	157.5	(15.5)	33.7	13.93
4. S+NCO	1	1	53.6	(5.3)	56.6	(5.6)	51.9	(5.1)	4.8	1.79
 	7	8	111.7	(11.0)	119.7	(11.7)	101.5	(10.0)	18.2	6.55
	25	28 (f'c)	163.1	(16.0)	179.6	(17.6)	145.2	(14.2)	34.4	15.51
5. MC+S	1	1	62.3	(6.1)	69.5	(6.8)	56	(5.5)	13.5	4.84
 	7	8	128.5	(12.6)	142.9	(14.0)	118.2	(11.6)	24.8	10.97
	25	28 (f'c)	208	(20.4)	214.7	(21.1)	191.0	(18.7)	23.6	9.76
6. WC+S+NCO	1	1	62	(6.1)	68.3	(6.7)	57.5	(5.6)	10.8	4.61
  	7	8	125	(12.3)	142.6	(14.0)	111.4	(10.9)	31.2	12.28
	25	28 (f'c)	188.5	(18.5)	207.7	(20.4)	169.7	(16.7)	38.0	14.10
7. WC+SC+NCO	1	1	56.5	(5.5)	60.6	(5.9)	53.3	(5.2)	7.3	2.69
  	7	8	117.2	(11.5)	128.6	(12.6)	107.3	(10.5)	21.4	8.89
	25	28 (f'c)	165.7	(16.3)	172.1	(16.9)	159.1	(15.6)	13.0	5.24
8. WC+SC+S	1	1	53.6	(5.3)	57.3	(5.6)	50.62	(5.0)	6.68	3.40
  	7	8	114.4	(11.2)	129.9	(12.6)	108.9	(10.5)	21	8.96
	25	28 (f'c)	155.1	(15.2)	172.8	(17.0)	139.9	(13.7)	32.9	11.70
9. WC+SC	1	1	60.4	(5.9)	62.8	(6.2)	56.7	(5.6)	6.1	2.50
 	7	8	119.1	(11.7)	121.9	(12.0)	113.5	(11.1)	8.5	3.25
	25	28 (f'c)	163.7	(16.1)	183.7	(18.0)	142	(13.9)	41.7	15.60
10.SC+NCO	1	1	60.7	(6.0)	62.9	(6.2)	57.8	(5.7)	5.1	1.97
 	7	8	116.2	(11.4)	126.4	(12.4)	104.5	(10.2)	21.9	7.94
	25	28 (f'c)	147.9	(14.5)	154.6	(15.2)	138.7	(13.6)	15.9	5.85
11. SC	1	1	61.5	(6.0)	64.9	(6.4)	57.9	(5.7)	7.0	3.03
	7	8	112.2	(11.0)	116.4	(11.4)	100	(9.8)	16.4	7.02
	25	28 (f’c)	163.8	(16.1)	169.7	(16.7)	158.6	(15.6)	11.2	3.97
12. P	1	1	61.2	(6.0)	65.0	(6.4)	59.4	(5.8)	5.6	2.28
	7	8	112.7	(11.1)	124.4	(12.2)	104.6	(10.3)	19.8	7.51
	25	28 (f’c)	163	(16.0)	176.6	(17.3)	150.8	(14.8)	25.8	11.98
13. PWB	1	1	64.2	(6.3)	68.8	(6.7)	58.2	(5.7)	10.6	5.14
	7	8	128.7	(12.6)	131.9	(12.9)	123.8	(12.1)	8.1	3.24
	25	28 (f'c)	154.6	(15.2)	168.5	(16.5)	147.1	(13.4)	21.4	8.63

From the graph, average fc vs. curing time in figure 3, it is possible to have a more specific idea of the strengths behavior reached by the dry mixtures in presence of a series number of curing methods, at one side, this graph allows the extract of the major projection methods at a production level, by another side, is possible to extract the most critical systems.

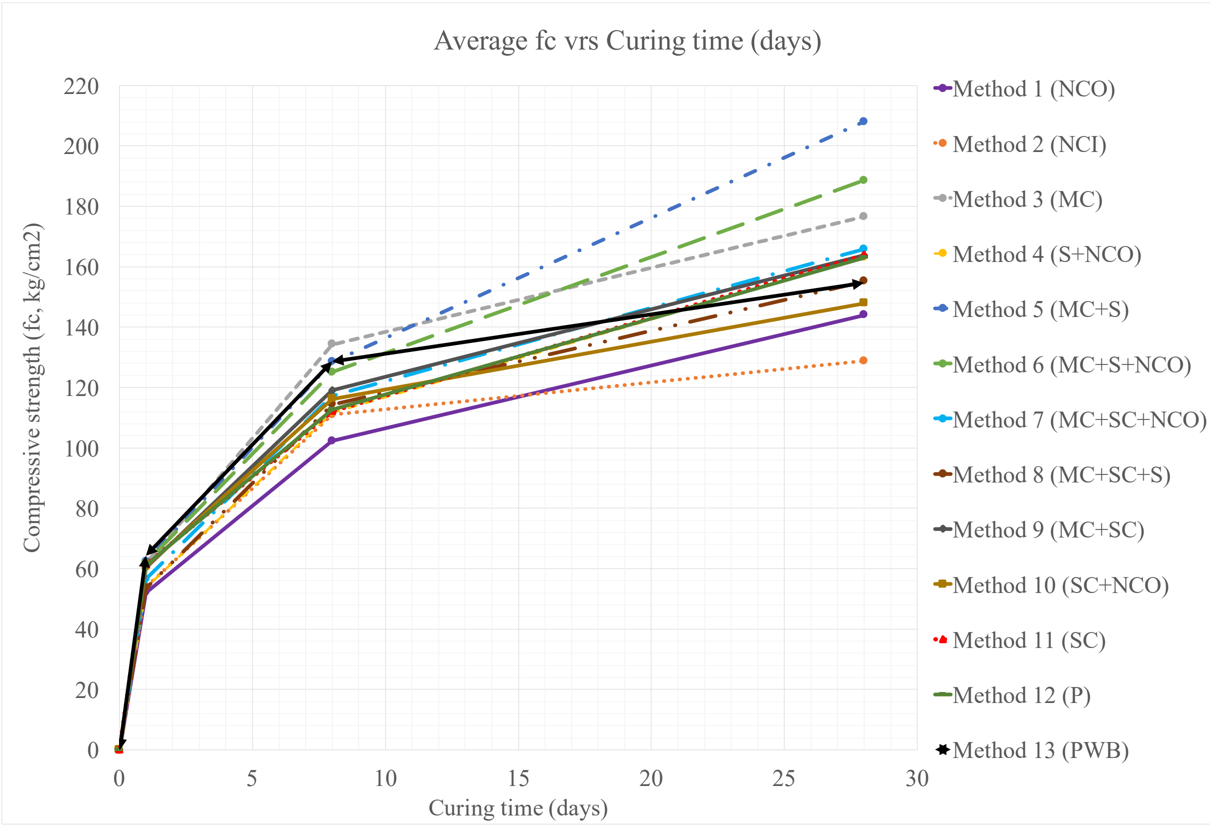


Figure 2: fc average of blocks exposed to different times and methods of cure

As can be seen in figure 3, the methods with the greatest projection are those that incur wet adhesion from the early ages of the blocks, such as method 5, 6, 7, 8 etc. Applying the curing system by means of a wet chamber in the first hours of the block, allows a partial hardening of the piece, as well as the humidity necessary for the hydration process to be continuous contributing in the gain in the compressive strengths to early ages. Figure 4 shows the lower part of the wet chamber simulations (polystyrene), once all have been placed in each respective site, it is necessary to place the whole serial system of micro sprinklers as soon as possible.

Figure 3: Blocks placed in the wet chambers simulation

Obviously one is in the presence of methods with satisfactory results, and once again demonstrate the positive effect of the cure as one of the fundamental factors that compose the compressive strength of the dry mixtures. Although method 5 presents greater efficiency in terms of gains in compressive strengths, it is not a viable system in its application. When it is mentioned that the method is not the most viable, it is basically summarized in the production processes, where usually cure systems are applied up to 7 days, which corresponds to approximately 70% of the expected compressive strengths, Including recommendations from the ACI [1] and the PCA[5]. At the manufacturing level, reducing the delivery times of the blocks provide a sensible economic improvement, additionally, the application of curing for 28 days incurs an over cost in the production processes.

For this and more reasons is that method 6 has been assigned as the most feasible, which means, the easiest, more effective and economical way a method can be applied, based on this, a series of comparisons between a critical method and the one of greater importance were carried out in order to obtain a percentage of the increase that is reflected in the gains of the compressive strengths due to the application of a suitable cure, means by which a correction factor is available that allows a considerable improvement in the compressive strengths attained in the concrete blocks.

Method 2 did not incur any additional cure, however, the blocks were also exposed to no weather or controlled temperature. As can be observed in the results, this system has the lowest resistance, although at the production level the blocks are always exposed to at least a minimal cure, in order to emphasize the importance of the cure in dry mixtures, has been considered as the critical method and will be the reference against the ideal system, in addition to this, method 2 is intended to refer to a cure performed in the yard in the summer period, which corresponds to high temperatures and lower precipitations.

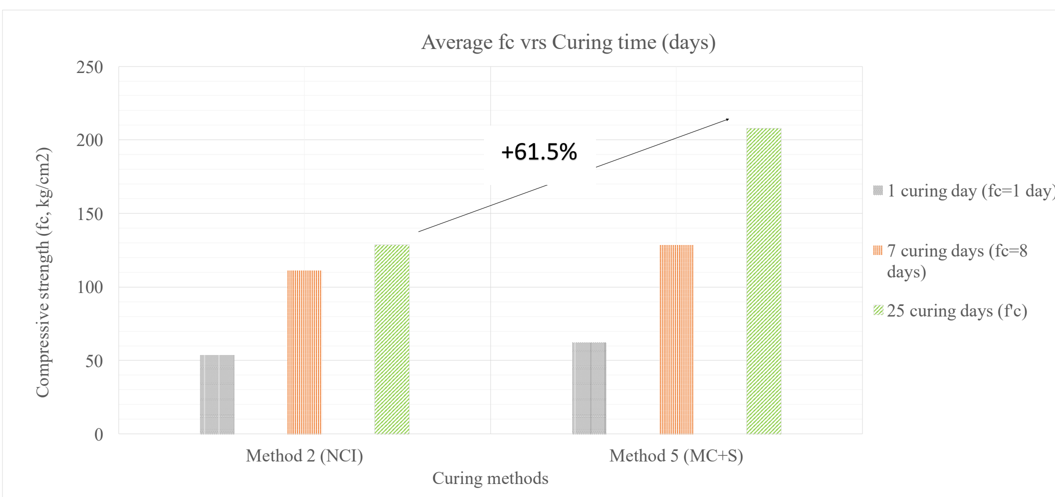


Figure 4: Increase in method 5 resistances compared to Method 2

Although the method 5 is not considered to be the most viable in its application, but the ideal in terms of the results obtained, a comparative was carried out in order to have a parameter of the benefit of the cure against a null curing system. As can be seen in figures 7 and 8, there is a considerable increase at 24 hours and 7 days, and an excessive increase at 28 days of up to 61.5%. Although the blocks are not dispatched within 28 days, their quality control analyzes are evaluated at 28 days.

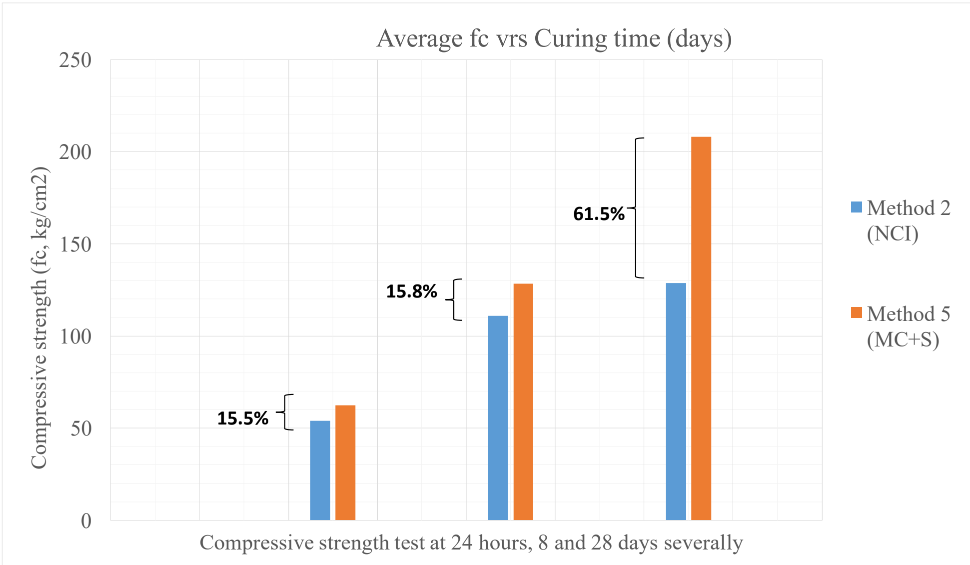


Figure 5: Comparison of method 2 against method 5 in the compression strengths obtained at 24 hours, 8 and 24 days

Table 2: Summary of methods of higher projection in the application of industrial production

fc, kg/cm2 (days)		1	8	28
Average fc				
Methods	Method 2 (NCI)	53.98	110.97	
	Method 5 (MR+S)	62.34	128.45	207.99
	Method 6 (MR+S+NCO)	61.97	124.99	188.54
	Method 7 (MR+WC+NCO)	56.50	117.18	165.72
	Method 8 (MR+WC+S)	53.60	114.38	155.08
	Method 12 (P)	61.21	112.70	162.96

As can be seen in Table 2, these are the 6 methods that meet the characteristics to be implemented at the production level (including the critical method number two), were assigned in this way not only by the compressive strengths obtained, but also because of their low cost in terms of improvements and ease of application. Obviously, it is necessary to emphasize the importance of curing in the first 24 hours of the block for its gain in the resistances, being the mixtures with a low water content, much of that moisture is consumed in the hydration process and by the relative humidity of the environment, which considerably reduces the gains in resistances. In addition to this, the wet tarpaulin system allows the presence of water in the early hours of concrete hardening, as well as the proper water of the mixture; However, it can damage the initial consistency of the blocks and also requires keeping it moist for continuous periods, which is inconvenient for long periods.

From Table 2, its possible to extract the analysis of method 2 (critical) vs. the system 6 (ideal).

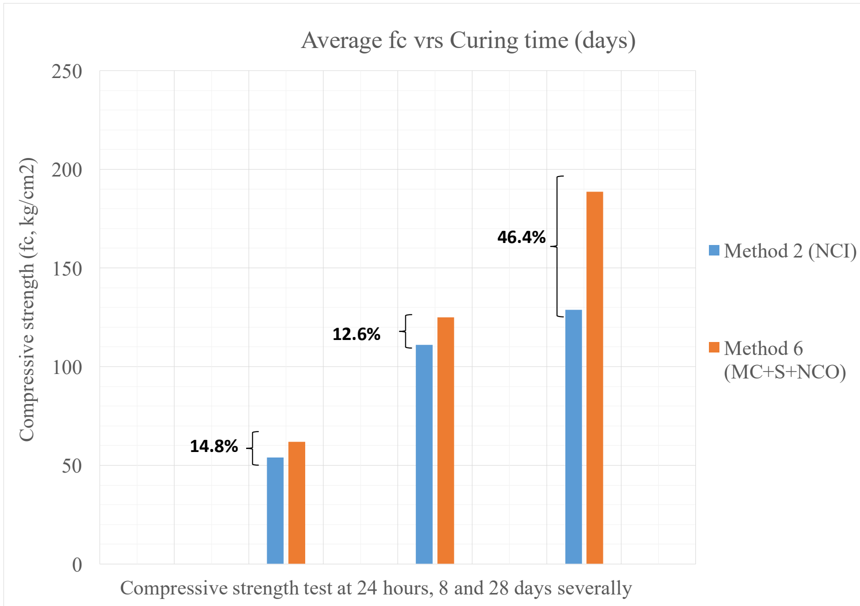


Figure 6: Comparison of method 2 vs. method 6 at different ages

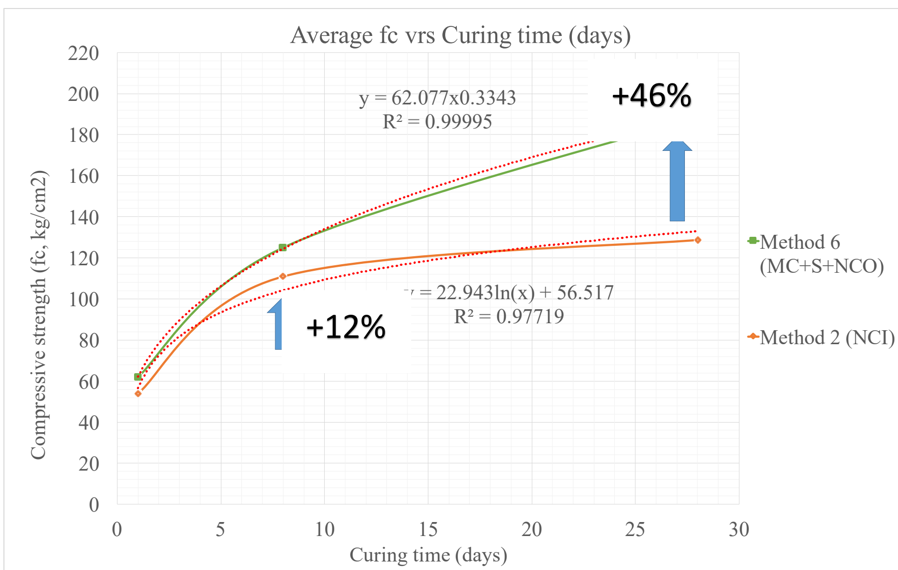


Figure 7: Comparison of the compressive strength of the method 6 vs method 2

According to figure 9 and 10 a percentage of the critical method has been obtained against the most viable method, which provides a very correct value of the correction that can be made in the blocks manufactured without any additional cure. As can be observed in figure 10, the obtained values at 28 days shown a 46% increase of the strengths generated in relation to a non-curing system, also presents a gain of 12.6% at 8 days.

In order of a recommendation, a graph of the methods with better results at 7 days of cure have been proposed (including method 2 with the critical strengths), which allows a projection of the dispatch times that can be performed in the plant with the improvements in cure. It is extremely important to emphasize that these results can be improved due to the methodology used in the project to extract the blocks from the curing chambers which reduced the curing time of the first 24 hours up to a 20- 25%.

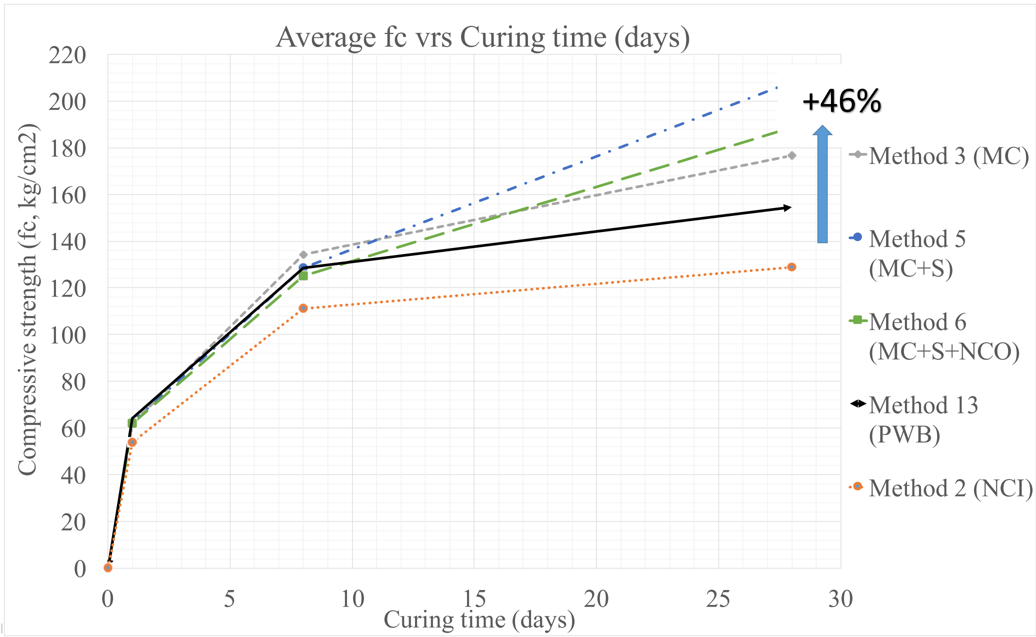


Figure 8: Methods with the highest compressive strengths obtained at 8 days

CONCLUSIONS

As can be seen in the strengths obtained from the concrete blocks tested and subjected to different curing methods, taking into consideration a zero cure method in relation to parts subjected to a curing in the yard only through daily precipitations (45 minutes daily per 18 days), ensures that a minimum curing process can increase the compressive strength of specimens made with dry mixtures up to 12% at 28 days. From the same data collected, it has been demonstrated that the low water content of the dry mix is not enough for the hydration process to occur during the initial 24 hours of the block, an aspect that is reflected in the compressive strengths and weights of the blocks at 28 days, a situation that has allowed to determine the importance in the application of curing by additional water in dry mixes at early ages.

Considering the climatic conditions of a tropical country like Costa Rica where there are only two well defined seasons (dry and rainy for 6 months each), the presence of high temperatures, excessive winds and the scarcity of rainfall in the dry season, causes a decrease in the resistances reached by the blocks. In the comparison between outdoors (in winter season) and no curing indoors method, this situation can be verified.

With the methodologies implemented, it has been possible to define an ideal method of cure applicable to the area of dry mixtures, allowing a low cost in its application at industrial level and a considerable increase in the compressive strengths, which corresponds to an increase of a 46 % of the strengths at 28 days in relation to uncured concrete blocks.

The application of 24 hour wet chamber cure method followed by 6 days with sprinklers, is considered the ideal method for block production in Costa Rica, since most of the factories have block storage rooms for early ages that can be adapted with micro sprinklers, in addition of the relatively economic adjustment that needs to be done to set sprinklers in the yards. Also, by the conditions of the country, get water by means of wells and recycling, turns out to be a simple and low cost method that contributes the develop of the "ideal method".

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