

# Application of Self-Curing Concrete Method Using Polyethylene Glycol

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**Abstract**– In this investigation the method of self-curing of concrete is applied using polyethylene glycol (PEG 400), with the aim of proposing an innovative alternative of curing concrete that suppresses the traditional external curing of the concrete indicated in ASTM C31, in order to obtain expected compression strength results, observing the development of concrete hydration processes. The experimental campaign included the production of 157 cylindrical specimens of dimensions 100×200 mm and 18 beams of dimensions 150×150×500 mm. Water-cement (w/c) ratios =0.70, 0.60 and 0.45 and strength tests at 7, 14 and 28 days were considered. Dosages of PEG 400 were used in 0.5%, 1% and 1.5% of the cement weight for the determination of the dosage that provides the best compressive strength results. Concrete properties were characterized such as splitting tensile strength, modulus of rupture, and its microscopic composition was observed using Scanning Electron Microscopy (SEM). Finally, it was obtained that at 28 days, the dosage of 1% of the cement weight for PEG 400, provides the most satisfactory results of compressive strength, splitting tensile strength and modulus of rupture for w/c = 0.70, 0.60 and 0.45.

**Keywords**-- Self-curing Concrete, Polyethylene Glycol, Splitting Tensile Strength, Modulus of Rupture, Scanning Electron Microscopy.

## I. INTRODUCTION

According to the critical scenario that manifests itself based on the deficiencies observed in the practice of concrete curing, which generates unsatisfactory characteristics of concrete, it is necessary to propose the use of products that can solve this problem from the design in order to create an alternative for suppressing the external curing process of concrete, considering the latter generates multiple uncertainties in the final strength of concrete, which varies according to the efficiency with which this procedure is developed.

ACI 308R-01 (2001) [1] and ASTM C 31 (2015) [2], propose the guide to curing concrete, describing curing methods and the materials used for these purposes. In addition, it exposes different types of curing according to the type of construction that is executed and the controls that are taken to guarantee the proper curing of concrete. Junaid (2015) [3] and Henkensiefken (2009) [4] provide a description and explanation about the internal curing of concrete and the importance of this technique to reduce the autogenous contraction and the formation of cracks in the concrete, Amaro (2002) [5] carried out a study of the performance of compressive strength of concrete according to traditional methods of external curing and describes its deficiencies. Baradan and Un (2011) [6] show the importance of temperature and humidity on the development of the mechanical properties of Portland cement under different curing regimes.

Sundaraman (2016) [8] investigate materials that act as self-curing agents in concrete and show the advantages of internal curing. Likewise, studies of self-curing concrete strength for different w/c ratios were carried out with polyethylene glycol of molecular weight 400 g/mol, used as self-curing agent.

Mousa, Mahdy, Abdel-Reheem, Yehia (2015) [9] investigate the characteristics of self-curing concrete using pre-saturated lightweight aggregate, as well as the use of micro silica and polyethylene glycol of molecular weight 200g/mol to compare the results offered by these products with regard to water retention and durability.

This research seeks to propose the use of an admixture that promotes the self-curing of concrete, as is the case with polyethylene glycol (PEG 400), material that acts as a potential self-curing agent, which leads to great benefits such as cost reduction related to the curing process, greater water retention to improve the performance of cement hydration, saving water as a natural resource since this material will not be used to the curing process, possibility of providing an effective curing process in areas with limited access to water.

### A.1 Concrete curing

The term "curing" is often used to describe the process by which concrete based on hydraulic cement matures and develops properties in a hardened state over time as a result of continuous hydration in the presence of sufficient water and adequate temperature. (ACI 308R, 2001) [1].

The curing of the concrete avoids self-drying, which is the internal drying of the concrete due to the water consumption resulting from the hydration of the cement. In relation to this, in mixtures of low a/c ratio, sealed against water loss or water entry, there is a greater risk that these mixtures can be dried internally. Thus, curing measures are required as soon as the concrete is at risk of drying and when such action damages the concrete or inhibits the development of the required properties (ACI 308R, 2001) [1].

### A.2 Self-curing or internal curing of concrete

Self-curing concrete means that no labor is required to provide water in the concrete, or even no external curing is required after placement. The properties of this concrete are at least comparable and even better than those of concrete with traditional curing. Self-curing is an "internal curing" system in which a water-soluble polymer is added to the concrete mix.

This method overcomes the difficulty of ensuring that construction personnel employ effective curing procedures since the internal curing composition is a component of the concrete mix (Krishna & Jaipal, 2017) [10]. Some materials that can provide internal water deposits are: lightweight aggregate, superabsorbent polymers (SAP) and shrinkage reducing admixture (SRA), such as polyethylene glycol.

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Currently, there are two main methods available for self-curing concrete. The first method uses lightweight aggregate (LWA) to supply an internal source of water, which can replace the water consumed by the chemical contraction during the hydration of the cement. The second method uses polyethylene glycol (PEG) that reduces the evaporation of water from the surface of the concrete and also helps in water retention (Abishek, 2016) [11].

Due to the difference in the chemical potential between the vapor and liquid phases, continuous evaporation of moisture takes place from the external surface of the concrete. The polymers added to the concrete mix mainly form hydrogen bonds with the water molecules and reduce the chemical potential of their molecules, which manifests itself in the reduction of vapor pressure, thus reducing the rate of evaporation of the surface (Daliya, 2016) [12].

### A.3 Polyethylene Glycol (PEG)

Polyethylene glycol, also known as polyethylene oxide (PEO), polyoxyethylene (POE) or macrogol, is a polyether produced by the condensation of ethylene oxide and water. The general formula of PEG is  $H(OCH_2CH_2)_nOH$ , where  $n$  is the average number of repeating oxyethylene groups, typically from about 4 to about 180. The low molecular weight compounds from  $n = 2$  to  $n = 4$  are diethylene glycol, triethylene glycol and tetraethylene glycol respectively, which are produced as pure compounds. The abbreviation (PEG) is called in combination with a numerical suffix that indicates the average molecular weight (Krishna & Jaipal, 2017) [10].

## II. EXPERIMENTAL DESCRIPTION

Concrete mixes were designed for each of the following water-cement ratios:  $w/c = 0.70, 0.60$  and  $0.45$ , which were selected for the most frequent use in the construction field for compliance with the usual strength requirements ( $w/c = 0.70, 0.60$ ), and durability requirements ( $w/c = 0.45$ ).

Concrete specimens of  $100 \times 200$  mm were produced according to ASTM C192 (2016) [13] to be subsequently tested by compressive strength at the ages of 7, 14 and 28 days, following the procedure of ASTM C39 (2015) [14] for each  $w/c$  ratio studied.

Specimens were placed in a room with homogeneous and uniform temperature conditions of  $23 \pm 2$  °C and relative humidity of 70%, in order to maintain homogeneous conditions in the samples until laboratory tests and to avoid uncertainties in the results, produced by humidity and temperature variations.

From the analysis of the results, the optimal dosage was determined by comparing the compressive strength results using a PEG 400 dosage of 0.5%, 1% and 1.5% of the cement weight, with the concrete standard.

With the defined optimum dosage of PEG 400, specimens were produced to determine other characteristics of the concrete at 28 days, such as splitting tensile strength, modulus of rupture, and Scanning Electron Microscopy (SEM) analysis.

### B.1 Materials

In the present investigation, crushed stone from the UNI quarry was used as coarse aggregate, whose granulometric distribution resembles spindle 6 according to ASTM; coarse sand from the JICAMARCA quarry was used as fine aggregate, likewise, SOL Portland Type I cement, potable water and as an admixture, the polyethylene glycol with molecular weight 400 g/mol (PEG 400) was used.

Main aggregate parameters were calculated in order to determine the characteristics of each aggregate, and the results are presented in Table 1.

TABLE I  
CHARACTERISTICS OF AGGREGATES

Characteristic	Fine aggregate	Coarse aggregate
Specific gravity	2.67	2.69
Loose bulk density. (kg/m <sup>3</sup> )	1632	1388
Bulk density by rodding (kg/m <sup>3</sup> )	1886	1569
Absorption (%)	0.60	1.00
Moisture content (%)	2.08	0.54
Nominal maximum size	-	3/4"
Fineness modulus	3.06	7.02

### B.2 Concrete mix proportion

The Walker methodology is used to obtain the best combination of aggregates for the relation  $w/c = 0.70$ . Then, for all the water-cement ratios ( $w/c = 0.70, 0.60$  and  $0.45$ ), it was decided to maintain the distribution of aggregates in 50% of sand and 50% of stone with respect to the total volume of aggregates prepared for the concrete mix, in order to consider a homogeneous distribution of aggregates in the 3 cases of study and by workability conditions.

The identification of the samples produced in the investigation are detailed in Table 2.

TABLE 2  
IDENTIFICATION OF SAMPLES

Ident.	State of curing	% PEG 400
SC +0.0%wc	Without curing	+0.0% cement weight
SC +0.5%wc	Without curing	+0.5% cement weight
SC +1.0%wc	Without curing	+1.0% cement weight
SC +1.5%wc	Without curing	+1.5% cement weight
C +0.0%wc	Cured in water all the time	+0.0% cement weight

Likewise, Table 3, Table 4 and Table 5 show the proportion of materials per m<sup>3</sup> corrected for moisture content and absorption of the aggregates for  $w/c = 0.70, 0.60$  and  $0.45$ , respectively.

TABLE 3  
CONCRETE MIX PROPORTION IN WET STATE BY MASS (KG) FOR  $w/c = 0.70$

Sample	Cement	Sand	Stone	Water	PEG400
SC +0.0%wc	311.4	904.9	895.5	209	-
SC +0.5%wc	311.4	904.9	895.5	209	1.56

SC +1.0%wc	311.4	904.9	895.5	209	3.11
SC +1.5%wc	311.4	904.9	895.5	209	4.67
C +0.0%wc	311.4	904.9	895.5	209	-

TABLE 4  
CONCRETE MIX PROPORTION IN WET STATE BY MASS (KG) FOR W/C = 0.60

Sample	Cement	Sand	Stone	Water	PEG400
SC +0.0%wc	363.3	880.3	875.5	209	-
SC +0.5%wc	363.3	880.3	875.5	209	1.82
SC +1.0%wc	363.3	880.3	875.5	209	3.63
SC +1.5%wc	363.3	880.3	875.5	209	5.45
C +0.0%wc	363.3	880.3	875.5	209	-

TABLE 5  
CONCRETE MIX PROPORTION IN WET STATE BY MASS (KG) FOR W/C = 0.45

Sample	Cement	Sand	Stone	Water	PEG400
SC +0.0%wc	484.4	828.6	822.7	210	-
SC +0.5%wc	484.4	828.6	822.7	210	2.42
SC +1.0%wc	484.4	828.6	822.7	210	4.84
SC +1.5%wc	484.4	828.6	822.7	210	7.26
C +0.0%wc	484.4	828.6	822.7	210	-

### B.3 Preparation of the samples

A total of 135 cylindrical concrete specimens of 100×200mm were produced according to ASTM C192 [13], which were tested in compressive strength at 7, 14 and 28 according to ASTM C39 [14] for each type of sample identified and for each w/c ratio.

In addition, 22 additional cylindrical concrete specimens of 100×200mm were produced according to ASTM C192 [13], for the performance of splitting tensile strength tests and Scanning Electron Microscopy (SEM) tests for standard concrete samples and samples with PEG 400 with 1% of the weight of the cement for each w/c ratio initially indicated.

Likewise, 18 prismatic beams of 150×150×500 mm were made for the execution of tests of modulus of rupture for samples of standard concrete and samples with PEG400 with 1% of cement weight for each w/c ratio.

## III. RESULTS AND ANALYSIS

### C.1 Results of compressive strength tests

The concrete specimens were tested according to ASTM C39 [14] for w/c = 0.70, 0.60 and 0.45. Fig. 1 shows tested samples.



Fig. 1. Concrete specimens tested by compressive strength

Table 6, Table 7 and Table 8 summarize the averages of compressive strength obtained at 7, 14 and 28 days for w/c=0.70, 0.60 and 0.45 in each of the identified samples.

TABLE 6  
AVERAGE COMPRESSIVE STRENGTH (KG/CM<sup>2</sup>) OBTAINED AT 7, 14 AND 28 DAYS FOR W/C = 0.70

Sample	7 days	14 days	28 days
SC +0.0%wc	174	187	208
SC +0.5%wc	187	210	231
SC +1.0%wc	211	220	247
SC +1.5%wc	205	219	238
C +0.0%wc	206	216	256

TABLE 7  
AVERAGE COMPRESSIVE STRENGTH (KG/CM<sup>2</sup>) OBTAINED AT 7, 14 AND 28 DAYS FOR W/C = 0.60

Sample	7 days	14 days	28 days
SC +0.0%wc	227	252	276
SC +0.5%wc	242	276	315
SC +1.0%wc	269	299	335
SC +1.5%wc	246	272	312
C +0.0%wc	265	296	343

TABLE 8  
AVERAGE COMPRESSIVE STRENGTH (KG/CM<sup>2</sup>) OBTAINED AT 7, 14 AND 28 DAYS FOR W/C = 0.45

Sample	7 days	14 days	28 days
SC +0.0%wc	318	336	366
SC +0.5%wc	353	410	441
SC +1.0%wc	392	449	480
SC +1.5%wc	350	406	434
C +0.0%wc	348	386	455

### C.2 Results of splitting tensile strength tests

The concrete specimens were tested according to ASTM C496 [15] for a / c = 0.70, 0.60 and 0.45. Fig. 2-3 show samples tested.



Fig. 2. Visualization of the failure in a concrete specimen by splitting tensile test



Fig. 3. Specimens of concrete tested by splitting tensile strength

Table 9 is shown below, which summarizes the average values of splitting tensile strength obtained at 28 days, for  $w/c = 0.70, 0.60$  and  $0.45$ .

TABLE 9  
AVERAGE SPLITTING TENSILE STRENGTH (KG/CM<sup>2</sup>) OBTAINED AT 28 DAYS FOR  
 $w/c = 0.70, 0.60$  Y  $0.45$

a/c	0.70	0.60	0.45
SC 1.0% - 28D	23.1	28	37.4
C 0.0% - 28D	23.9	26.8	35.6

### C.3 Results of flexural strength tests on beams

Concrete beams were tested for the determination of their modulus of rupture according to ASTM C78 [16] for  $w/c = 0.70, 0.60$  and  $0.45$ . Fig. 4-5 show some of the beams tested.

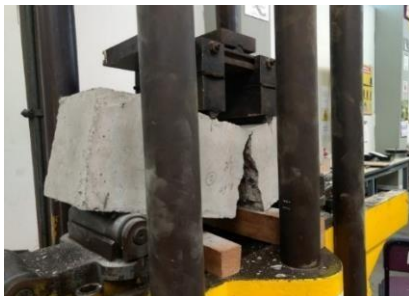


Fig. 4. Visualization of the failure in a concrete beam by flexural strength test



Fig. 5. Concrete specimens tested by flexural strength

Table 10 is shown below, which summarizes the average values of modulus of rupture obtained at 28 days, for  $w/c = 0.70, 0.60$  and  $0.45$ , tested in  $150 \times 150 \times 500$  mm beams.

TABLE 10  
AVERAGE MODULUS OF RUPTURE (KG/CM<sup>2</sup>) OBTAINED AT 28 DAYS  $w/c = 0.70, 0.60$  Y  $0.45$

a/c	0.70	0.60	0.45
SC 1.0% - 28D	32.0	37.8	47.1
C 0.0% - 28D	34.3	39.6	46.1

### C.4 Results of Scanning Electron Microscopy (SEM) tests

The images corresponding to the microscopic characteristics of concrete specimens for  $w/c = 0.45$  are shown below. Fig. 6-7 show the German Scanning Electron Microscope ZEISS model EVO 10 and the placement of the concrete sample.

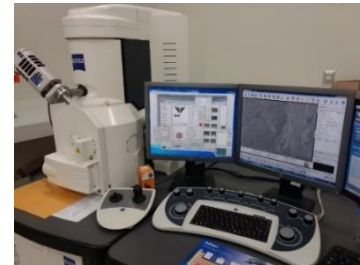


Fig. 6. Scanning Electron Microscope

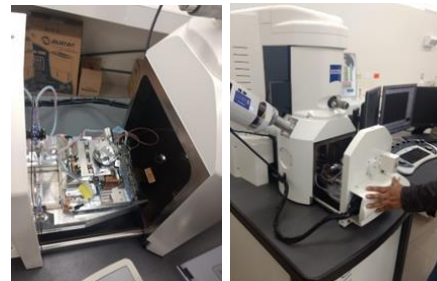


Fig. 7. Sample placement in the Scanning Electron Microscope

*Results for w/c = 0.45 at 7 days*

Fig. 8-9 show the microscopic characteristics of a 15×15×10 mm concrete sample coded as SC + 1.0% wc for w/c= 0.45 at 7 days, observed in the scanning electron microscope with a 10 000x and 50 000x amplification, respectively.

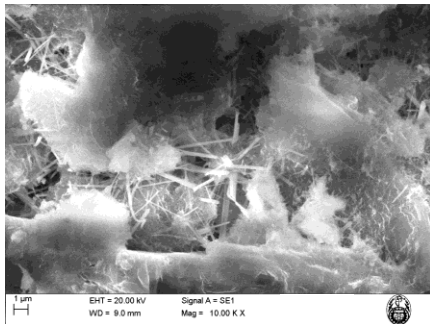


Fig. 8. Observation in the scanning electron microscope of sample SC + 1.0% wc at 7 days for w/c = 0.45, with an amplification of 10 000x

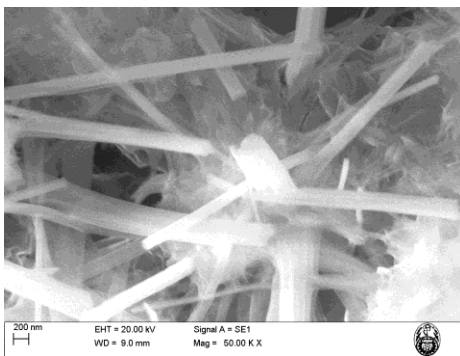


Fig. 9. Observation in the scanning electron microscope of sample SC + 1.0% wc at 7 days for w/c = 0.45, with an amplification of 50 000x

Fig. 10-11 show the microscopic characteristics of a 15×15×10 mm concrete sample coded as C + 0.0% wc for w/c=0.45 at 7 days, observed in the scanning electron microscope with a 10 000x and 50 000x amplification, respectively.

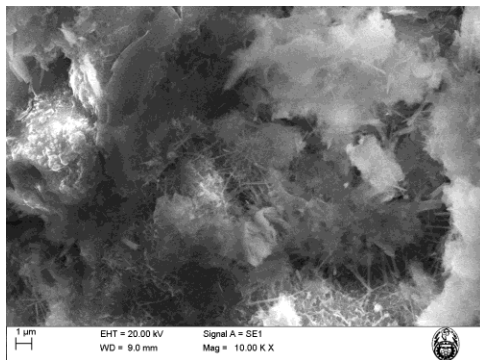


Fig. 10. Observation in the scanning electron microscope of sample C + 0.0% wc at 7 days for w/c = 0.45, with an amplification of 10,000x

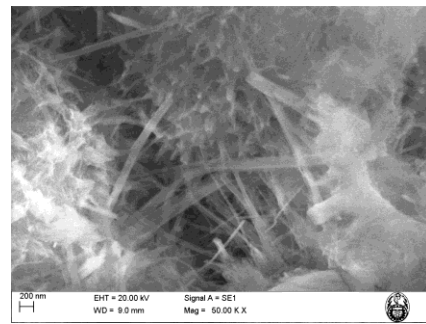


Fig. 11. Observation in the scanning electron microscope of sample C + 0.0% wc at 7 days for w/c = 0.45, with an amplification of 50 000x

*Results for w/c = 0.45 at 28 days*

Fig. 12-13 show the microscopic characteristics of a 15×15×10 mm concrete sample coded as SC + 1.0% wc for w/c=0.45 at 28 days, observed in the scanning electron microscope with a 10 000x and 50 000x amplification, respectively.

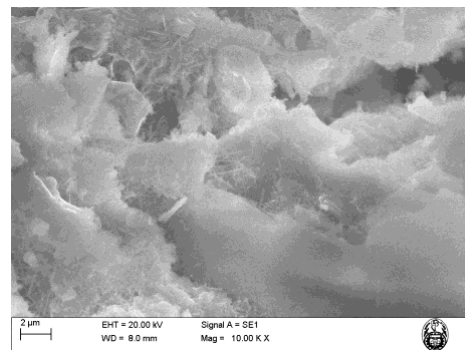


Fig. 12. Observation in the scanning electron microscope of sample SC + 1.0% wc at 28 days for w/c = 0.45, with an amplification of 10 000x

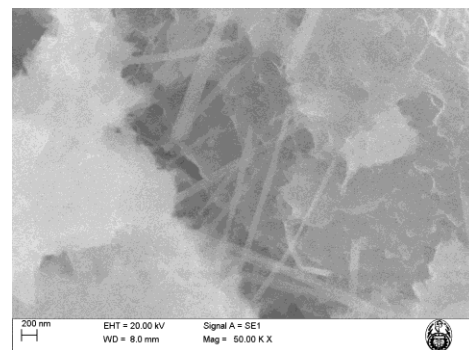


Fig. 13. Observation in the scanning electron microscope of sample SC + 1.0% wc at 28 days for w/c = 0.45, with an amplification of 50 000x

Fig. 14-15 show the microscopic characteristics of a 15×15×10mm concrete sample coded as C + 0.0% wc for w/c=0.45 at 28 days, observed in the scanning electron microscope with a 10 000x and 50 000x amplification, respectively.



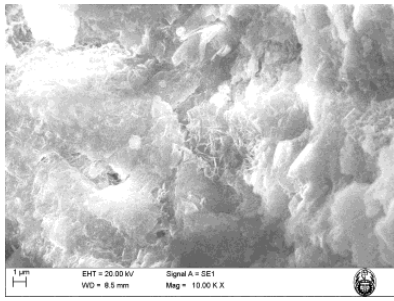


Fig. 14. Observation in the scanning electron microscope of sample C + 0.0% wc at 28 days for w/c = 0.45, with an amplification of 10,000x

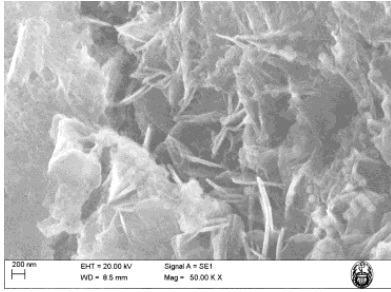


Fig. 15. Observation in the scanning electron microscope of sample C + 0.0% wc at 28 days for w/c = 0.45, with an amplification of 50 000x

### C.5. Analysis of results

Many equations have been published to characterize the relationship between compressive strength and curing time, among these, the exponential and hyperbolic equations have been recommended in ASTM C 1074 [17]. The exponential dependence of compressive strength with curing time (S (t)) is expressed by the equation:

$$S(t) = S_u \cdot \exp\left[-\left(\frac{\tau}{t}\right)^\beta\right] \quad (1)$$

and allows to estimate the maximum compressive strength value of a type of concrete.

Where,

- S<sub>u</sub>: is the maximum compressive strength to reach
- t: time in hours
- τ: time constant
- β: constant form

#### Analysis of compressive strength results for w/c = 0.70

From Table 6, Fig. 16-19 and Table 11 are constructed, where it is observed that for w/c = 0.70, the best compression characteristics are found for specimens containing 1% of PEG400 with average compressive strength 2.4% higher than the average compressive strength of the standard concrete at 7 days (See Fig. 16). At 14 days, 1.9% higher than the average compressive strength of the standard concrete (See Fig. 17). At 28 days, 3.5% lower than the average compressive strength of the standard concrete (See Fig. 18).

Fig. 19 shows the compressive strength achieved by this concrete over the curing time. The results of the strength data

adjustment achieved versus curing time with equation [1] are shown in Table 11 and the adjustment curve for sample SC + 1.0% is shown in Fig. 20.

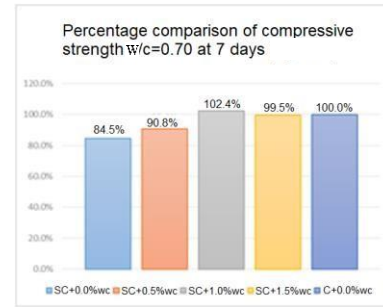


Fig. 16. Percentage comparison of compressive strength obtained at 7 days for w/c = 0.70

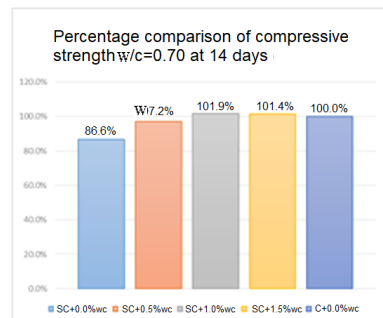


Fig. 17. Percentage comparison of compressive strength obtained at 14 days for w/c = 0.70

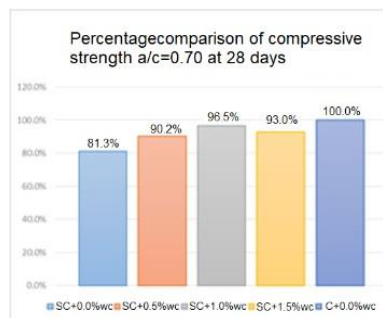


Fig. 18. Percentage comparison of compressive strength obtained at 28 days for w/c = 0.70

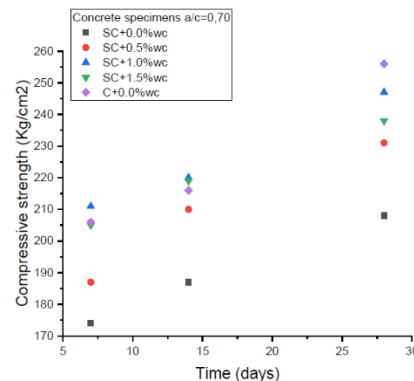


Fig. 19. Compressive strength values obtained at 7, 14 and 28 days for w/c=0.70

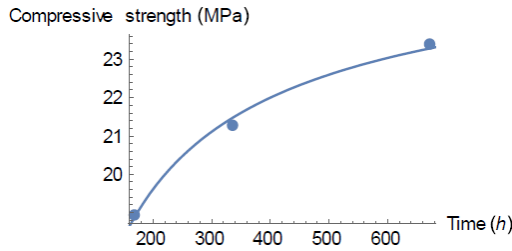


Fig. 20. Compressive strength obtained at 28 days for SC + 1.0% wc; w/c= 0.70 and adjustment curve with exponential function.

TABLE 11  
RESULTS OF THE NON-LINEAR ADJUSTMENT OF THE COMPRESSIVE STRENGTH AVERAGES (KG/CM<sup>2</sup>) OBTAINED AT 7, 14 AND 28 DAYS FOR W/C = 0.70, USING THE COMPRESSIVE STRENGTH-CURING TIME EXPONENTIAL FUNCTION

	Su (MPa)	$\tau$ (h)	$\beta$
SC +0.0%wc	23.37	30.99	0.71
SC +0.5%wc	26.62	34.98	0.68
SC +1.0%wc	26.79	30.0	0.80
SC +1.5%wc	26.06	24.99	0.75
C +0.0%wc	29.89	41.01	0.65

*Analysis of compressive strength results for w/c = 0.60*

From Table 7, Fig. 21-24 are constructed, where it is observed that for w/c = 0.60, the best compression characteristic corresponds to specimens containing 1% of PEG400 with average compressive strength 1.5% higher than the average compressive strength of the standard concrete at the age of 7 days (See Fig. 21). At 14 days, 1% higher (See Fig. 22), and at 28 days, 2.3% lower (See Fig. 23).

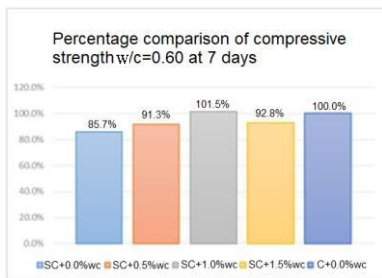


Fig. 21. Percentage comparison of compressive strength obtained at 7 days for w/c = 0.60

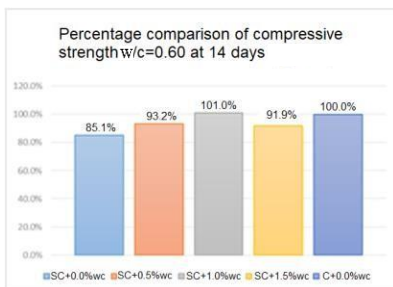


Fig. 22. Percentage comparison of compressive strength obtained at 14 days for w/c = 0.60

The increase in compressive strength versus curing time for this concrete is shown in Fig. 24. From the adjustment of these experimental data with equation [1], the data recorded in Table 12 are obtained and the adjustment curve for sample SC + 1.0% is shown in Fig. 25.

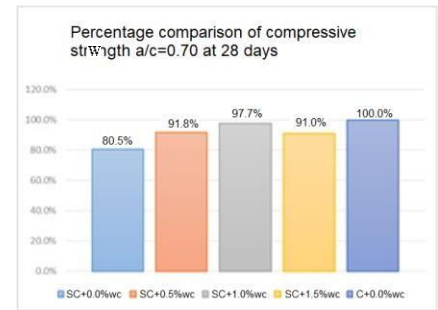


Fig. 23. Percentage comparison of compressive strength obtained at 28 days for w/c = 0.60

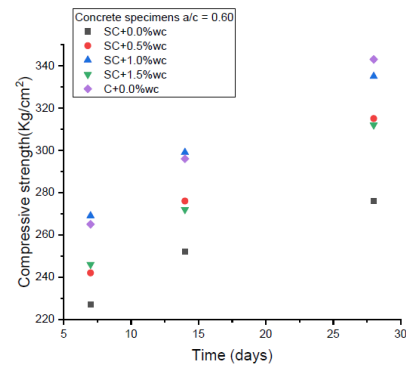


Fig. 24. Compressive strength values obtained at 7, 14 and 28 days for w/c = 0.60

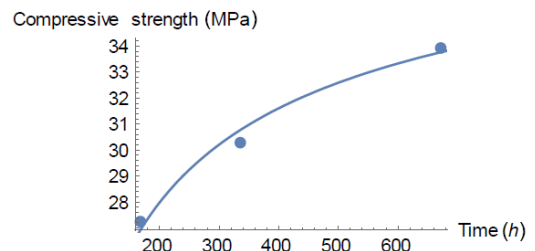


Fig. 25. Compressive strength obtained at 28 days for SC + 1.0% wc; w/c=0.60 and adjustment curve with exponential function.

TABLE 12  
RESULTS OF THE NON-LINEAR ADJUSTMENT OF THE COMPRESSIVE STRENGTH AVERAGES (KG/CM<sup>2</sup>) OBTAINED AT 7, 14 AND 28 DAYS FOR W/C = 0.60, USING THE COMPRESSIVE STRENGTH-CURING TIME EXPONENTIAL FUNCTION

	Su (MPa)	$\tau$ (h)	$\beta$
SC +0.0%wc	31.89	30.99	0.65
SC +0.5%wc	38.87	51.01	0.62
SC +1.0%wc	41.61	34.98	0.53
SC +1.5%wc	36.62	45.97	0.69
C +0.0%wc	38.39	61.01	0.92

*Analysis of compressive strength results for w/c = 0.45*

From Table 8, Fig. 26-29 are constructed where it is observed that for w/c = 0.45, the best compression characteristics are found for specimens containing 1% of PEG400 with average compression resistance 12.6% higher than the average compressive strength of the standard concrete at 7 days (See Fig. 26). At 14 days, 16.3% higher than the average compressive strength of the standard concrete (See Fig. 27). At 28 days, 5.5% higher than the average compressive strength of the standard concrete (See Fig. 28).

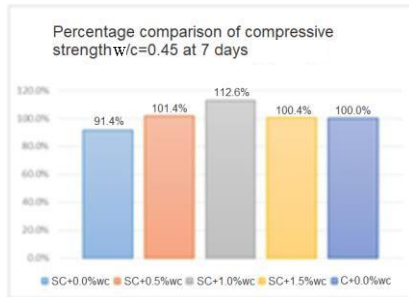


Fig. 26. Percentage comparison of compressive strength obtained at 7 days for w/c = 0.45

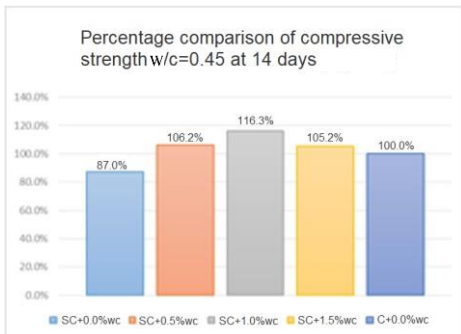


Fig. 27. Percentage comparison of compressive strength obtained at 14 days for w/c = 0.45

The increase in compressive strength versus curing time for this concrete is shown in Fig. 29. From the adjustment of these experimental data with equation [1], the data recorded in Table 13 are obtained and the adjustment curve for sample SC + 1.0% is shown in Fig. 30.

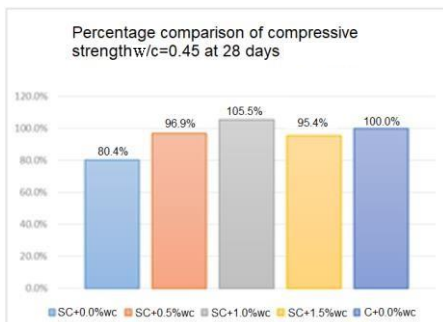


Fig. 28. Percentage comparison of compressive strength obtained at 28 days for w/c = 0.45

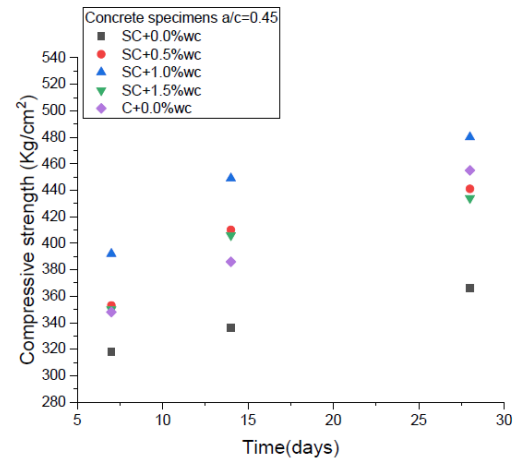


Figure 29. Compressive strength values obtained at 7, 14 and 28 days for w/c=0.45

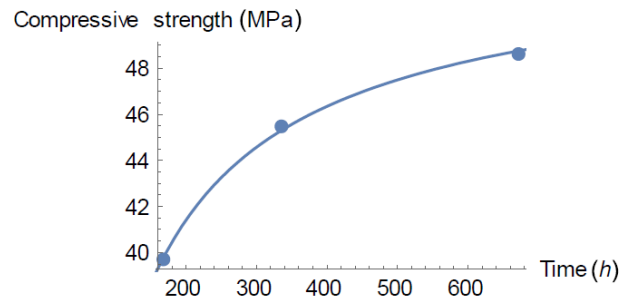


Figure 30. Compressive strength obtained at 28 days for SC + 1.0% wc; w/c=0.45 and adjustment curve with exponential function.

TABLE 13  
RESULTS OF THE NON-LINEAR ADJUSTMENT OF THE COMPRESSIVE STRENGTH AVERAGES (KG/CM2) OBTAINED AT 7,14 AND 28 DAYS FOR W/C = 0.45, USING THE COMPRESSIVE STRENGTH-CURING TIME EXPONENTIAL FUNCTION

	Su (MPa)	τ (h)	β
SC +0.0%wc	40.47	20.99	0.68
SC +0.5%wc	48.25	47.99	0.97
SC +1.0%wc	53.57	38.99	0.83
SC +1.5%wc	47.53	46.99	0.97
C +0.0%wc	53.97	51.98	0.68

*Analysis of splitting tensile strength results for w/c = 0.70*

From Table 9, Fig. 31 is constructed, where it is observed that, for w/c = 0.70, at 28 days, the best splitting tensile strength characteristics are found for specimens containing 1% of PEG400 with an average splitting tensile strength of 23.9kg/cm<sup>2</sup>, 3.3% lower than the average splitting tensile strength of the standard concrete, which has 23.1 kg/cm<sup>2</sup>.



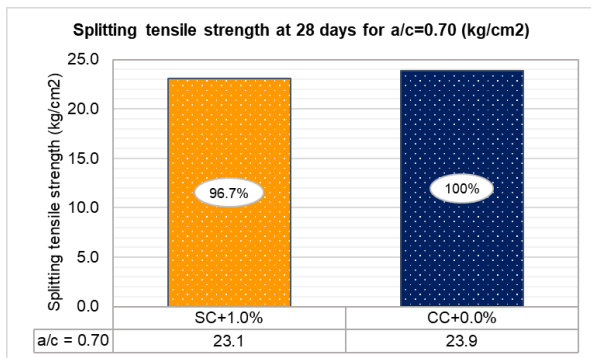


Figure 31. Results of splitting tensile strength at 28 days for w/c = 0.70

*Analysis of splitting tensile strength results for w/c = 0.60*

From Table 9, Fig. 32 is constructed, where it is observed that, for w/c = 0.60, at 28 days, the best splitting tensile strength characteristics are found for specimens containing 1% of PEG400 with an average splitting tensile strength of 28 kg/cm<sup>2</sup>, 4.5% higher than the average splitting tensile strength of the standard concrete, which has 26.8 kg/cm<sup>2</sup>.

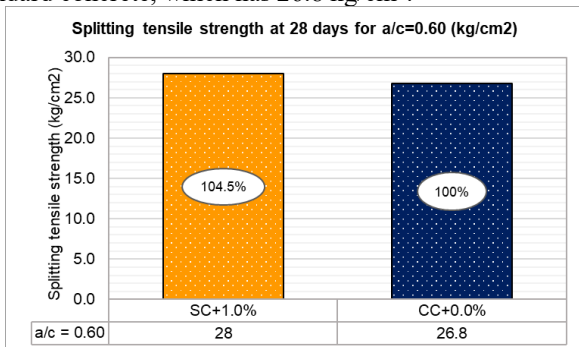


Figure 32. Results of splitting tensile strength at 28 days for w/c = 0.60

*Analysis of splitting tensile strength results for w/c = 0.45*

From Table 9, Fig. 33 is constructed, where it is observed that, for w/c = 0.45 at 28 days, best splitting tensile strength characteristics are found for specimens containing 1% of PEG400 with an average splitting tensile strength of 37.4kg/cm<sup>2</sup>, 5.1% lower than the average splitting tensile strength of the standard concrete, which has 35.6 kg/cm<sup>2</sup>.

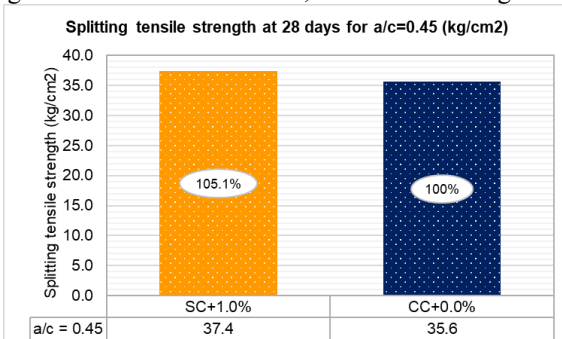


Figure 33. Results of splitting tensile strength at 28 days for w/c = 0.45

*Analysis of modulus of rupture results for w/c = 0.70*

From Table 10, Fig. 34 is constructed, where it is observed that, for w/c = 0.70 at 28 days, the best modulus of rupture characteristics are found for specimens containing 1% of PEG400 with an average modulus of rupture of 32kg/cm<sup>2</sup>, 6.7%

lower than the average modulus of rupture of the standard concrete, which has 34.3 kg/cm<sup>2</sup>.

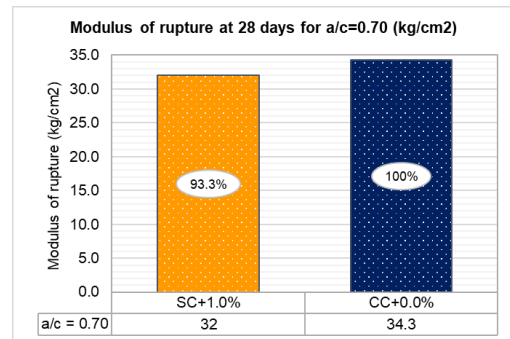


Figure 34. Results of modulus of rupture at 28 days for w/c = 0.70

*Analysis of modulus of rupture results for w/c = 0.60*

From Table 10, Fig. 35 is constructed, where it is observed that, for w/c = 0.60 at 28 days, the best modulus of rupture characteristics are found for specimens containing 1% of PEG400 with an average modulus of rupture of 37.8kg/cm<sup>2</sup>, 4.5% lower than the average modulus of rupture of the standard concrete, which has 39.6 kg/cm<sup>2</sup>.

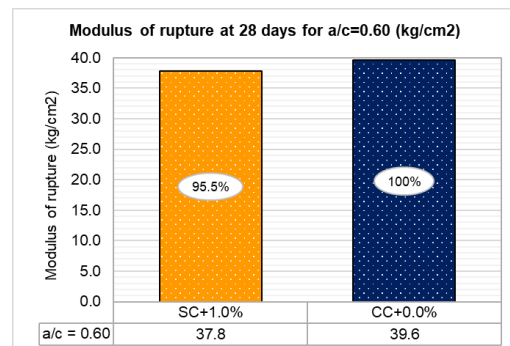


Figure 35. Results of modulus of rupture at 28 days for w/c = 0.60

*Analysis of modulus of rupture results for w/c = 0.45*

From Table 10, Fig. 36 is constructed, where it is observed that, for w/c = 0.45 at 28 days, the best modulus of rupture characteristics are found for specimens containing 1% of PEG400 with an average modulus of rupture of 47.1kg/cm<sup>2</sup>, 2.2% higher than the average modulus of rupture of the standard concrete, which has 46.1 kg/cm<sup>2</sup>.

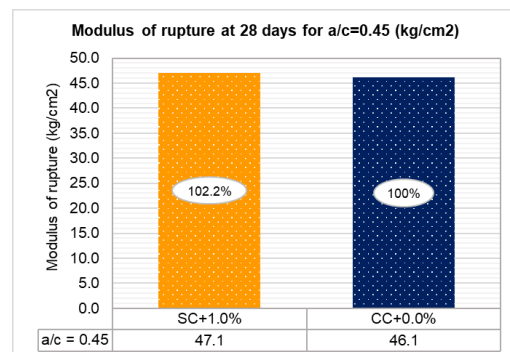


Figure 36. Results of modulus of rupture at 28 days for w/c = 0.45

#### *Analysis of results of SEM tests for w/c = 0.45 at 7 days*

The analysis encompasses the qualitative comparison of the images recorded with the Scanning Electron Microscopy (SEM) tests, based on Fig. 8-11. Thus, it is observed that, at 7 days, the characteristics of the formation of the crystals, (concrete hydration products) are similar both for samples containing 1% of PEG400 without curing and for samples that not contain PEG400 and that were cured in water all the time.

Likewise, in both cases the multidirectional bonds between cement particles that begin to become denser in the first days are observed more clearly, which confers the increase in strength as these hydration products become denser over time.

#### *Analysis of results of SEM tests for w/c = 0.45 at 28 days*

The analysis covers the qualitative comparison of the images recorded with the Scanning Electron Microscopy (SEM) tests, from Fig. 12-15. At 28 days, the characteristics of the formation of the crystals, (concrete hydration products) are similar both for samples containing 1% of PEG400 without curing and for samples that not contain peg 400 and that were cured in water all the time.

Likewise, in both cases the multidirectional bonds between cement particles are observed in less quantity and clarity compared to 7 days, since for this age almost all of the reactions that confer resistance to concrete have already occurred; consequently, the formation of new hydration products has a very low rate and finally consolidated crystals are observed.

#### IV. CONCLUSIONS

On the basis of experimental tests, results and analysis, the following conclusions are drawn:

1. The application of PEG 400 as a self-curing method provided comparable and superior results of compressive strength, splitting tensile strength and flexural strength in comparison with the conventionally cured concrete for w/c=0.70, 0.60 and 0.45. Therefore, it is confirmed that PEG400 fulfills the self-curing function.

2. The optimal dosage of PEG 400 determined was 1% of the cement weigh, which provided the best results in compressive strength for w/c= 0.70, 0.60 and 0.45 studied at 7, 14 and 28 days. Thus, it was the dosage chosen to study other properties of concrete.

3. In respect of compressive strength, at early ages (7 and 14 days), higher results and growth rates are obtained in sample SC+1.0%wc in comparison with sample CC+0.0%wc, for w/c=0.70, 0.60 and 0.45, which could be explained due to the fact that PEG 400 promotes better hydration in early days because of its capacity for retaining humidity. In addition, at 28 days, the growth rate in compressive strength decreased compared to the increase recorded in early days, which could be attributed to the fact that remaining hydration reactions were produced in sample CC+0.0%wc because of availability of water curing, what conferred a better performance in strength gain in comparison with sample SC+1.0%wc.

4. PEG 400 performs best for low w/c ratios, which is particularly evident in the case of w/c = 0.45 with 1% of PEG 400, in which at 28 days, an increase of 5.5% in compressive strength, a growth of 5.1% in splitting tensile strength and a rise of 2.2% in modulus of rupture are obtained with respect to the

conventionally cured concrete.

5. SEM test provides a qualitative description of the characteristics of crystal formation (products of the concrete hydration), which demonstrates that similar characteristics are shared for samples SC +1.0%wc and CC +0.0%wc. Likewise, in both cases the concentrated multidirectional links among cement particles are clearly observed at 7 days, and the finally consolidated crystals at 28 days.

6. The application of self-curing method using PEG 400 results effective and ecological since it leads to saving water, seen as a scarce natural resource, due to the fact that water will not be used to cure concrete. Moreover, the implementation of this method proposes an effective curing alternative in areas with limited access to water.

#### ACKNOWLEDGMENT

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