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# Application of maturity method to estimate compressive strength of mass concrete

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**Abstract.** The correlation between the maturity index and the compressive strength of concrete is validated for mixtures with strengths of 2000, 2500, 3000 and 3500 PSI, which are the most used in the civil engineering field. Temperature probes DS18B20 connected by the 1-Wire protocol to the Raspberry Pi 3 card were used to census the data and calculate the maturity index. The concrete mixtures presented A/C ratios of 0.820, 0.748, 0.680 and 0.623, which are consistent with those used in the construction industry. Compressive strength tests were performed every 24 hours during a 28-day test scenario in order to understand the behavior of concrete throughout the curing process. From the values of mechanical resistance to compression obtained in the control ages of 7 and 14 days it is inferred that the concrete has a normal hardening, likewise when comparing the experimental results of the resistance to compression, with those found using the method of maturity, it was possible to identify that at early ages (less than 10 days) they present uncertainties greater than 10% while at ages greater than 10 days of curing this error does not exceed 5%. In general, it was evidenced that the assembly carried out with the Raspberry pi 3 card and DS18B20 probes reliably allowed the monitoring, recording and storage of temperature and time data during the entire curing process.

## 1. Introduction

Commercially there are several types of concrete that depending on their composition and dosage exhibit different values to compression [1,2] which are evaluated with standardized tests that reflect the behavior and compliance of the material [3]. Therefore, it is necessary to have tools to predict the compressive strength during the curing process through non-destructive tests to achieve time reduction.

There are non-destructive testing methods based on the exothermic reaction generated during contact of cement with water [4], this reaction produces a change of enthalpy (total system energy), generating a temperature variation in the volume of concrete during the curing process.

Considering the combined effects of time and temperature during the curing process, the maturity method [5,6] predicts compressive strength by means of the maturity index [7,8,9].

The purpose of the present research is to know the resistance to compression by means of non-destructive tests at early ages and to estimate which will be the maximum resistance value at 28 days, for this the Nurse - Saul method was used, which is based on a linear relation [10], between the maturity index and a time interval. With the above, it was possible to obtain 1 mathematical correlation for each resistance, this mathematical correlation allows to know the state of the concrete at any age within the curing period without being necessary to carry out destructive tests to the newly constructed concrete structures and with this to affect the integrity of the same ones.



## 2. Methodology

In order to obtain data, we worked together with compression tests and the collection of temperatures during the curing process. Four batches of 87 cylinders each were melted, with a different resistance for each batch, of which 3 of these cylinders have a temperature probe for a total of 372 concrete cylinders.

### 2.1. Mixture design

It was worked with the method ACI committee 211-1 [11] which is standardized, in the obtained parameters are observed that as the resistance to compression increases the relation a/c decreases as well as the quantity of aggregate that must be used in the concrete mixture in Table 1 the values obtained for the design of worked mixture in each one of the resistances are presented.

**Table 1.** ACI method mixing designs.

A/C	0.820	0.748	0.680	0.623
Cement	1.000	1.000	1.000	1.000
Fine aggregate	3.895	3.556	3.256	2.985
Coarse aggregate	4.661	4.164	3.661	3.269
Settlement (cm)	5			

### 2.2. Temperature probes

To measure the temperature values, DS18B20 probes were used, which were connected by means of the 1-Wire communication protocol to a Raspberry Pi 3 Model B development card in which an application was programmed and executed using the Python 3 programming language. The temperature sensor was placed in the middle of a concrete cylinder and to one side the equipment used for data acquisition was installed, as shown in Figure 1.

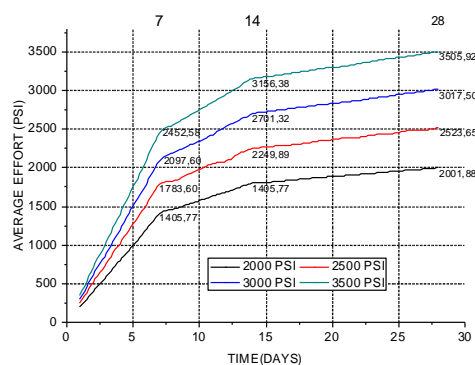


**Figure 1.** Acquisition system connection diagram.

## 3. Results

### 3.1. Compression tests

The daily compression tests were carried out for each of the proposed resistances. Figure 2 shows the values obtained and shows the behavior in the control ages at 7, 14 and 28 days of curing.



**Figure 2.** Resistances obtained in compression tests.

Taking into account Figure 2, it is evident that the compressive strength values obtained at 7 and 14 days are 70% and 90% respectively of the maximum expected compression value at 28 days, it can be inferred that it is a concrete with normal hardening [12,13].

3.2. Temperature recording

The measurements were made using 12 temperature probes DS18B20, 1 for each cylinder, 3 for each concrete resistance, simultaneously and in parallel, with a time interval of 1 minute, performing real time monitoring, sampling, conversion and storage of data taken from the temperature probes, were developed data acquisition system based on.

In the Figure 3 shows the temperatures obtained during the 28 days of curing for each of the resistances. For all monitored resistances, a temperature peak is evident before the first three days, similar to that expressed in the following way [14] whose graphs even describe two temperature peaks, the first due to the use of accelerants and the second largest due to the exothermic reaction generated by the contact of cement with water [15].

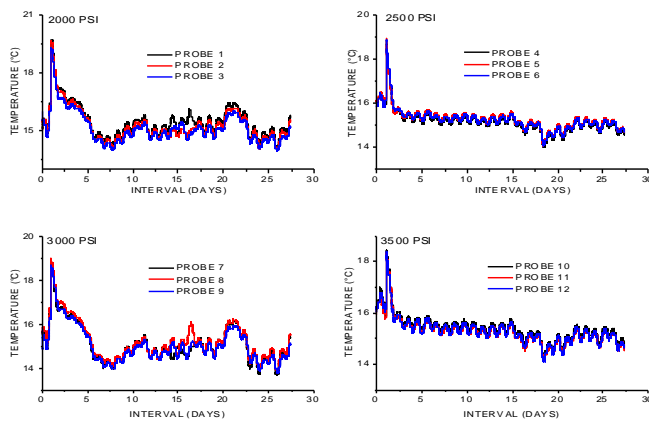


Figure 3. Temperatures for the proposed resistances during the 28 days of curing.

In order to obtain the mathematical expression for each resistance presented in Figure 4, we worked with the average of the maturity indices of the three probes using the Nurse-Saul method and the average of  $f'_c$  when 3 cylinders per day failed.

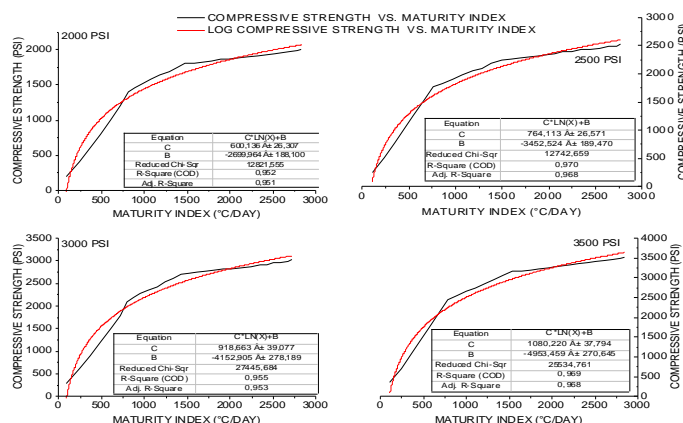


Figure 4. Compressive strength vs. maturity index.

The analysis of the graphs shown in Figure 4, is evaluated by a logarithmic trend line type (see Equation (1)).

$$Y = c \cdot \ln x + b \tag{1}$$

Where,  $Y$  is the dependent variable,  $x$  is the independent variable,  $c$  is the coefficient 1 and  $b$  is the coefficient 2.

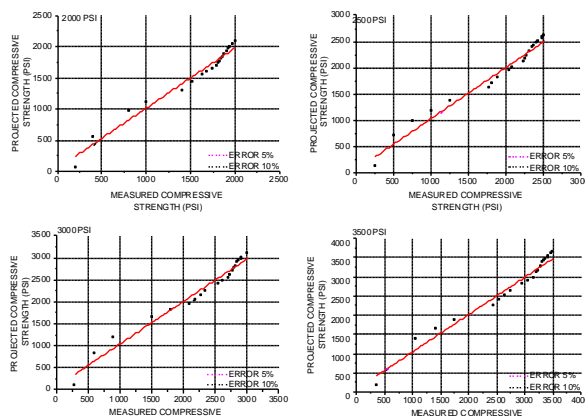
Taking into account Equation (1) and the values  $c$  and  $b$  obtained (see Figure (4)), we obtain (see Table (2)), which presents the mathematical models predicted by  $f'_c$  for each of the resistances proposed.

**Table 2.** Values for trend line and expression for each resistance.

Resistance	Values obtained			Mathematical expression
	PSI	C	B	
2000	600.136	-2699.964	0.951	$f'_c = 600.136 \ln(M) - 2699.964$
2500	764.114	-3452.525	0.968	$f'_c = 764.114 \ln(M) - 3452.525$
3000	918.663	-4152.906	0.953	$f'_c = 918.663 \ln(M) - 4152.906$
3500	1080.221	-4953.459	0.968	$f'_c = 1080.221 \ln(M) - 4953.459$

Where,  $f'_c$  is the resistance of concrete to compression at any age (MPa) and  $M$  is the maturity of the concrete ( $^{\circ}\text{C}\cdot\text{day}$ ).

Finally, once the mathematical models described in Table 2 have been found, each one is validated by comparing the results obtained in the compression tests and the use of the expressions found above. To calculate the percentage error for each of the resistances presented in Figure 5, the percentage error values obtained for each of the resistances are represented.



**Figure 5.** Percentage error for each of the resistances in the 28-day scenario.

Once the maturity index parameters have been obtained, by means of the Nurse-Saul method, it is possible to project  $f'_c$  at any age, although there is a high percentage error during early ages, this error tends to decrease when a stabilization of the curing temperature is achieved, reaching values of  $< 10\%$ , as it is also recorded in other research [16].

Nurse-Saul's maturity method in this case is highly reliable due to the acquisition of minute-by-minute data decreasing the influence of uncontrolled variables as was the case [14] which could not implement the Nurse-Saul method because the value of  $R^2$  was very low, performed finite element analysis.

#### 4. Conclusions

It was possible to determine that the behavior of the maturity index with respect to the time along the measurements, presents a linear growth for each one of the resistances initially raised, it is to note that once the temperature values are had and the measurement times it is easy to calculate the maturity index by means of the Saul-Nurse equation.

Validation between the maturity index and the compressive strength of concrete cylinders was achieved using the Nurse-Saul method with a % error < 10%.

Once made the graphs Maturity index vs resistance to compression and applying the logarithmic tendency line it can be observed that this adjusts in a coherent way to the obtained data, this can be evidenced in the values of  $R^2$ , which allow to have a reliability of 96%.

Taking into account the graphs of Temperature vs Time, it was possible to determine that minimum temperature data should be taken 52 hours after pouring the concrete because after this time the temperature tends to stabilize, not in a linear way but the increases and decreases in the temperature values are very small.

It was possible to identify that at early ages (less than 10 days) there are uncertainties greater than 10% while at ages greater than 10 days of curing this error does not exceed 5%.

It was evidenced that the assembly carried out with the Raspberry pi 3 card and DS18B20 probes reliably allowed the monitoring, recording and storage of temperature and time data during the curing process.

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