Assessment the maturity concept in concrete with the addition of rice husk ash

Evaluación del concepto de madurez en hormigón con adición de cenizas de cascarilla de arroz

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Abstract

Steam curing is a process used to accelerate cement hydration reactions with the purpose of enhancing the mechanical strength of concrete at early ages, since hydration reactions are temperature dependent. To evaluate the influence of temperature on the development of mechanical properties of concrete the maturity concept was used. This method estimates the development of these properties according to the temperature history of concrete along the curing process. The temperature influence is indicated through the apparent activation energy (AE) value. The higher the AE value, the higher the energy amount will be necessary to start reactions, and thus the velocity of these reactions will be affected by temperature. This work is based on an experimental study of steam-cured concrete made with 5% and 10% of rice husk ash (RHA) addition in which the development of some mechanical properties was investigated. The rice husk ash used was obtained from uncontrolled combustion of rice husk, in an open chamber, without any temperature control or burning time. The mechanical property investigated was the compressive strength. Results indicate the influence of RHA addition and its dosage on the hydration reactions of cement and the mechanical properties of steam-cured concretes.

Keywords: *Concrete, rice husk ash, steam curing, maturity*

Resumen

La cura termal es un proceso utilizado para acelerar las reacciones de hidratación del cemento portland con el objetivo de obtener beneficios de resistencia mecánica a edades tempranas del hormigón, puesto que la temperatura opera en la velocidad de estas reacciones. Para una mejor evaluación de la influencia que ejerce la temperatura sobre el desarrollo de las propiedades mecánicas del concreto, se utiliza el concepto de madurez. El método de madurez estima el desarrollo de las propiedades mecánicas del concreto relacionado con la historia de las temperaturas durante el proceso de curado. La influencia de la temperatura puede ser indicada por la energía de activación (EA) aparente. Cuanto mayor sea el valor de la EA, mayor será la potencia necesaria para iniciar la reacción y, por lo tanto, la velocidad de estas reacciones se verá afectada por la temperatura. Este trabajo presenta los resultados de la determinación experimental de la resistencia a la compresión del hormigón fabricado con adición de cenizas de cascarilla de arroz (CCA), producido por la combustión no controlada de la corteza, en cámara abierta, sin control de la temperatura ni del tiempo de combustión. Como propiedad mecánica, se investigó la resistencia a la compresión. Los resultados señalan la influencia de la adición de CCA y su posología en las reacciones de hidratación del cemento y las propiedades mecánicas del hormigón con cura termal.

Palabras clave: Hormigón, cenizas de cascarilla de arroz, cura termal, madurez

1. Introduction

1.1 Maturity method

The maturity method was created with the intention to estimate the development of the properties of the concrete relating them with the historical temperature during the curing process, in maturity functions that involve time and temperature (Scoares et al., 2006). In civil construction, the maturity method is used to determine the approached time it takes the concrete to reach "in loco" a desired compressive strength, analyzing the description of temperature to which occurs the cure and in samples analyzed in the laboratory with controlled temperatures. The use of the thermal cure in the concrete is essentially used to reduce the curing time of the parts that requires high rotation of the forms.

The increase of the curing temperature of concrete speeds up the chemical reactions of the hydration of the cement, conferring larger initial strength and reducing the time of removal of form work. However, second (Peres et al., 2007), any property mechanics or physics of the concrete that is related to the hydration degree could be reached by the maturity method, and not summarizing them to the process to estimate the compressive strength.

The maturity concept was first introduced relating it to the compressive strength law of the profit of resistance with maturity: "One same mixture of concrete with one exactly maturity factor - measured a function of temperature and time - has, approximately, the same resistance any that is the combination of temperature and time to reach the maturity factor"(Barbosa et al., 2005).

(Peres et al., 2007) considered the relation of the maturity to the relative degree of development of the compressive strength, which in turn modified the law of Saul 1951: "One same mixture of concrete to one exactly the maturity degree (measured as a function of temperature and time) has, approximately, the same relative resistance any that is the combination of temperature and time to reach the maturity degree".

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(Salvador Filho et al., 2002) suggested that the simple product time x resistance would be capable to have the same cure effect as the steam in the profit of compressive strength. The function of Nurse-Saul assumes the following form, much spread out due to its simplicity, as it shows Equation 1:

$$M(t) = \Sigma (Ta - To). \Delta t \qquad (1)$$

M (t) = *factor of maturity at age t (°C.h);*

Δt = *time interval (h);*

T_a = *average of the temperature in a time interval Δt (°C);*

T_o = *base temperature (°C).*

The function developed for Freiesleben - Hansen and Pedersen (FHP), based on the model of Arrhenius for dependence of a reaction with the temperature, are most usual for application of the maturity method, with the inclusion of a parameter related to the thermal sensitivity of the reaction, called apparent activation energy, as well as sample Equation 2:

$$te = \sum_0^t \left[\exp \frac{Ea}{R} \left(\frac{1}{T} - \frac{1}{Tr} \right) \right] . \Delta t \qquad (2)$$

Ea = *apparent activation energy;*

R = *gas constant universal (8,314 J/mol.K);*

T = *absolute temperature of the concrete during the time interval Δt (K);*

T_r = *temperature of reference (k).*

1.2 Activation energy

In accordance with (Barbosa et al., 2005), in order ti use the application of the maturity method are necessary the knowledge of a parameter of thermal sensitivity of the mixture is necessary, as well as evaluating the dependence of the speed of the reaction of cement hydration with the temperature called apparent activation energy (AE).

According to (Fairbairn et al., 2002), the activation energy results in the idea that the molecules must possess a minimum amount of kinetic energy to react. This energy is necessary to transform the reagents and products. In the exothermic reactions (case of the cement hydration) the reagents are in a state of bigger energy than the products. Thus being, the activation energy is the difference between the energy necessary to activate the reaction and the level of energy of the reagents.

In the same temperature, reactions that have a very high demanding value of activation energy are said slow reactions, to the step that low values of AE are indicating of reactions that occur quickly. Bigger values of AE indicate a necessity of the greater energy to initiate the reaction, thus implying that this reaction will be more vulnerable to the influence of the temperature (Fairbairn et al., 2002).

Qualitatively the theory of collision explains well the four factors that influence the speed of reactions (Scoares et al., 2006; Barbosa et al., 2005 and Fioriti et al., 2012):

1) *The speed of the chemical reaction depends on the nature of the chemical reagents because the activation energy is different of a reaction from another one;*
2) *The speed of the reaction depends on the concentration of the reagents, because the number of collisions increases when the concentration is increased;*
3) *The speed of the reaction depends on the temperature, because an increase of the temperature makes molecules to be moved faster, increasing the frequency of the collisions;*
4) *The speed of the reaction depends on the presence of catalysts, in a way with that the collisions if become more effective.*

According to Arrhenius, the speed of a chemical reaction is a function of the named constant tax (kt) is follows Equation 3:

$$kt = A.\exp\left(\frac{-E}{RT}\right) \qquad (3)$$

kt = *constant tax;*

A = *constant or factor of frequency.*

According to (Peres et al., 2007) the frequency factor is used to quantify the probability that the collisions occur in directions favorable to the beginning of the chemical reaction, and with located atoms of such form in order to make possible new links. If treating reactions cement hydration, the use of the term apparent activation energy becomes more adequate, since they are heterogeneous processes with diverse reactions that occur simultaneously.

2. Material and methods

2.1 Materials

- ***Cement***

The cement type used in this research was high early strength Portland Cement CPV-ARI PLUS. All their characteristics were, according to the NBR 5733 (ABNT, 1991). Physical and chemical properties of cement were listed in Table 1.

- ***Aggregates***

The fine aggregate used is natural sand with a fineness modulus of 2.25 and specific gravity 2.58 g/cm^3. The coarse aggregate (basalt rock) has a maximum size of 19 mm and specific gravity 2.96 g/cm^3.

- ***Superplasticizer***

A superplasticizer of third generation of concrete was used. This superplasticizer is suitable for the production of high performance concrete. It facilitates extremely high water reduction, high flowability as well as internal cohesiveness. It was the Viscocrete 5 from Sika Brazil.

- ***Rice husk ash (RHA)***

Rice husk was burnt approximately 48 hours under uncontrolled combustion process. The burning temperature was within the range 600ºC to 850ºC (Floriti et al., 2013). The ash obtained was ground in a ball mill for 30 minutes and its appearance color was gray.

The physical and chemical characteristics were determined according to the NBR 5733 (ABNT, 1991), Table 2. In addition, a laser diffraction particle size analyzer was used to determine the particle size distribution of RHA.

Table 1. *Physical and chemical properties of cement*

Blaine specific surface (cm^2/g)		6916
Specific gravity (g/cm^3)		3.08
Initial setting time		1:48
Compressive strength (MPa)	3 days	33.4
	7 days	38.8
	28 days	45.0
Chemical ingredients	SiO_2	23.89
	Fe_2O_3	2.72
	Al_2O_3	8.91
	CaO	51.27
	MgO	4.48
	SO_3	3.55
	Na_2O	0.18
	K_2O	0.96

Table 2. *Physical and chemical properties of RHA*

Blaine specific surface (cm^2/g)		16196
Specific gravity (g/cm^3)		2.16
Mean particle size (μm)		12.34
Passing # 325 (%)		96.6
Chemical ingredients	SiO_2	92.99
	Fe_2O_3	0.43
	Al_2O_3	0.18
	CaO	1.03
	MgO	0.35
	$S\hat{O}_3$	0.10
	$Al_2O_3 + Fe_2O_3$	0.61
	$SiO_2 + Al_2O_3 + Fe_2O_3$	93.50
	Na_2O	0.02
	K_2O	0.72

2.2 Composition of the concrete mixtures

Table 3 shows the mixtures used in the composition concrete. The cement was substituted by the RHA in mass, in dosages of 0% (C), 5% (5C) and 10% (10C). The superplasticizer was dosed in 0.2% of the mass of cement + RHA for the mixtures without ash addition and for 5% of ash. For the mixture with 10% of ash, the dosage was of 0.3%of superplasticizer. Slump for each trace was fixed in 120±20 mm.

After that, they had been molded cylindrical specimens of dimensions 10x20 cm and tested to the simple compressive strength. The tests had been carried through with ages of 7 and 28 days, with curing in a moist chamber.

Table 3. *Composition of the concrete mixtures*

Cement	Sand	Coarse aggregate	W/C	Cement (kg/m^3)		
				C	5C	10C
1	1.33	2.27	0.42	490.0	465.5	441.0

2.3 Experimental determination of the energy of activation (Ea)

The method of determination of the apparent energy of activation of the concrete considered for C1074 (ASTM, 1998) is carried through from the compressive strength of the mortar of the studied concrete.

- ***Molding and cure***

The mortar specimens had been mixed manually and placed in cubical molds with 5x5x5 cm. The instant the water was placed in the mixture was written down as being the initial time. After molded, the specimens had been placed in the respective places of cure. The temperatures used were 30°C, 55°C and 80°C. The specimens to cure at 55°C and 80°C were first placed in a steam chamber up to the age of the first break, then after demolding, are brought to the thermal bath. After being taken to the thermal bath, the specimens were placed in a humid chamber to cure at 30°C until the time of the first rupture.

- ***Tests of resistance***

During the initial period of the cure, a specimen was removed for compressive strength test, marked as the final time the instant value of resistance reached approximately 4 MPa. The final time minus the initial (in the instant in that the water is added to the mix) determined the interval of time of the first age of rupture. From here, the five following ruptures were made in ages with the double of time of the immediately previous age. Six specimens had been tested by age, as shown in Figure 1.

For the thermal curing cylindrical specimens with dimensions 100x200 mm that had been molded, a part was taken for the humid cure and the other part to the thermal cure. The specimens used for the thermal cure had been sealed with plastic film to hinder the loss of humidity during the process. During the process, temperature is monitored by thermocouples installed in six specimens. For this, copper pipes are placed on specimens, where the thermocouples, are filled with oil and sealed. The data recording was carried through with digital multimeters with automatic system of acquisition. The readings had been made in intervals of five minutes.

After this procedure, the specimens were immediately placed in the equipment of thermal cure, in an already determined temperature the 80°C. The cure is carried through a steamed environment and saturated in the constant temperature, having a small variation only in the instant where the specimens are removed for tests.

The removal of the specimens was made at intervals of 1 hour, while in a cure cycle of 6 hours. The specimen's compressive strength was testedas soon as they were removed. The specimens cured in humid chamber had been tested at 7 and 28 days.

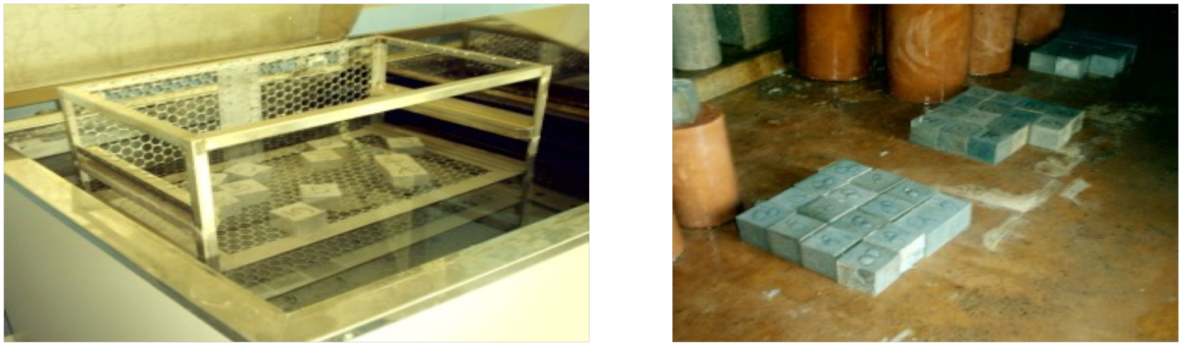

Figure 1. *Specimens thermal bath in a humid chamber, respectively*

3. Results and analises

- ***Calculation of the apparent activation energy (AE)***

The Tables 4, 5 and 6 with the final values of the AE for the used mixtures and the necessary comments are presented. With values of k and the temperatures in ºC, the graph for the determination was made To (ºC), that it is the base temperature, temperature below of which is assumed that the hydration reactions do not occur. Its value is taken by the intersection of the straight line in x-axis (temperature), Figure 2.

The value of Q is taken from the graph with the values of ln (k)for the inverse one of the temperature in Kelvin (1/K). Q is the inclination of the straight line, and is used in the equation that determines the value of AE. The Equation 4 to get the value of AE:

$$AE = \frac{QxR}{1000} \tag{4}$$

Where R is the universal gas constant (8.314 J/mol.K)

Table 4. *AE (control mixture)*

T (ºC)	T (K)	1/K	k	ln (k)
30	303	0.0033	0.4863	-0.7209
55	328	0.0030	4.0782	1.4057
80	353	0.0028	5.6248	1.7272
To (ºC)		**Q**	**Ea (KJ/mol)**	
21.94		5324.80	44.27	

Table 5. *AE (mixture 5C)*

T (ºC)	T (K)	1/K	k	ln (k)
30	303	0.0033	0.6022	-0.5072
55	328	0.0030	3.0243	1.1067
80	353	0.0028	4.5239	1.5094
To (ºC)		**Q**	**Ea (KJ/mol)**	
20.37		4371.10	36.34	

Table 6. *AE (mixture 10C)*

T (ºC)	T (K)	1/K	k	ln (k)
30	303	0.0033	0.5238	-0.6466
55	328	0.0030	3.9895	1.3837
80	353	0.0028	5.9973	1.7913
To (ºC)		**Q**	**Ea (KJ/mol)**	
22.99		5293.20	44.01	

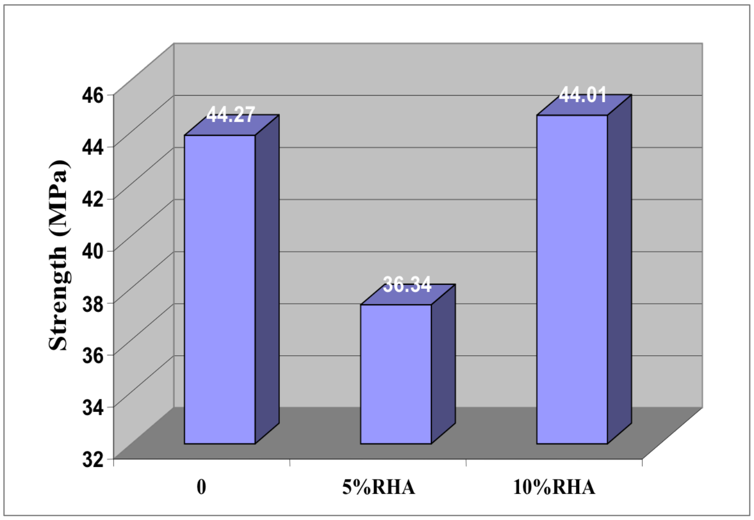

Figure 2. *AE for the mixtures*

- ***Humid cure***

As it shows Table 7, the two dosages of RHA provide resistance gain to the concrete. For the 28 days, the mixture 5C got 25.8% more than the resistance than the mixture control.With 10% of RHA, the resistance gain at 28 days was off 11.9%.

Table 7. *Compressive strength*

Mixtures	7 days	28 days
	(MPa)	(MPa)
C	46.2	48.9
5C	53.3	61.5
10C	46.28	54.7

- ***Calculation of the maturity***

The calculation of the index of maturity of the analyzed concrete was carried through in agreement C1074 (ASTM, 1998), whose procedure allows to express this index in terms of factor of maturity (Equation 1) or age equivalent (Equation 2). In this work, the results had been express for the two equations and are shown to follow.

For the calculation of the factor of maturity, the use of the value of base temperature of the concrete, determined during the attainment of the values of AE of the analyzed mixtures is necessary, made previously in accordance with the procedures of C1074 (ASTM, 1998). Figure 3 show the relation enters the factor of maturity and the evolution of the compressive strength and Figure 4 show to the relation with the age equivalent.

The curves of trends added to the data on the graphs represent the relations between the maturity index and the compressive strength of the concrete, being the same ones used to estimate the resistance of concrete cured under other conditions of temperature.

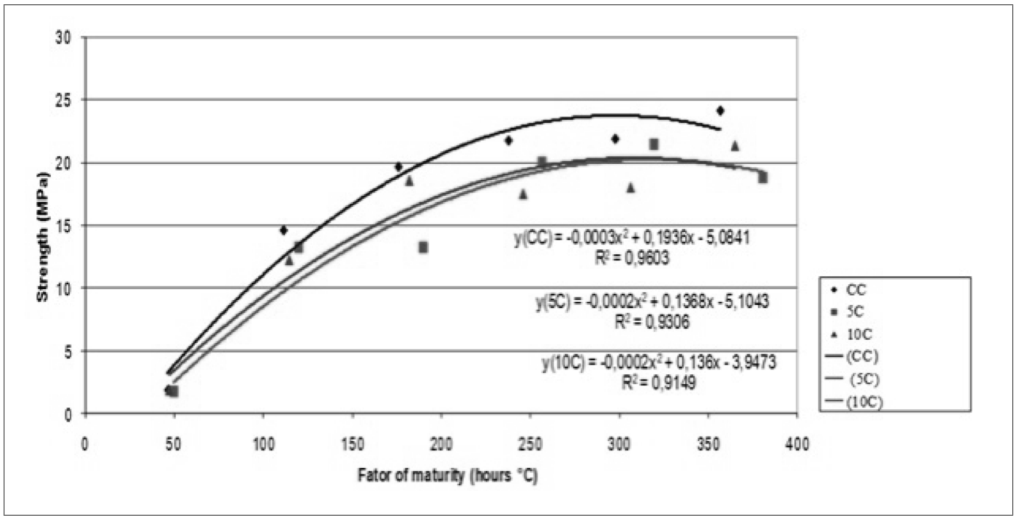

Figure 3. *Factor of maturity versus compressive strength*

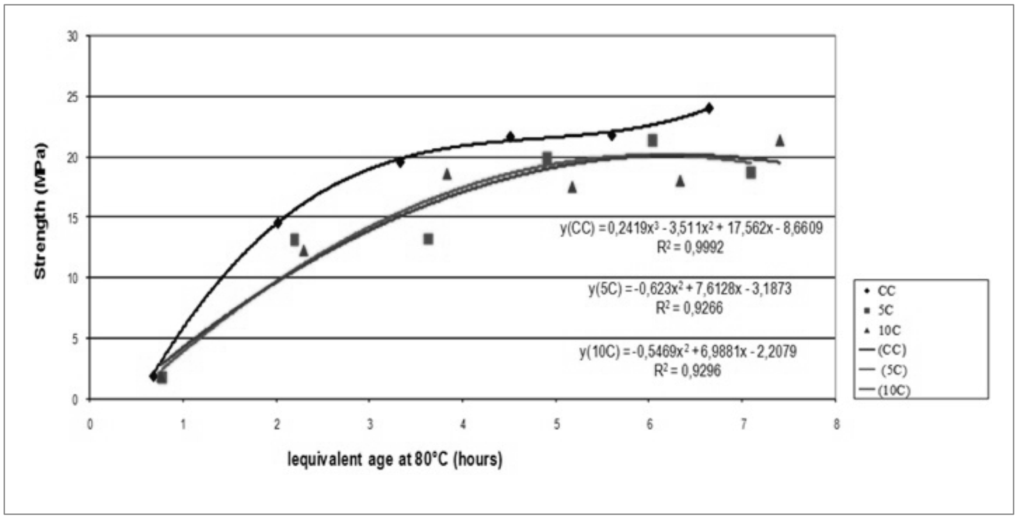

Figure 4. *Equivalent age versus compressive strength*

4. Conclusion

In the analysis of the results presented in this work we can verify the influence of the addition of the RHA in the behavior of the concrete, as much in the humid cure as in the thermal cure, with the use of the concept or method of the maturity. In the humid cure, it is important to observe that the resistance gain occurs in both two evaluated ages, for both the dosages of use RHA, being the lesser dosage (5%) the one that it got better results, attaining 25.8% at 28 days. In the case of the thermal cure, the results taken for the resistance had inverse behavior, with the RHA addition not promoting gain of resistance in relation to the mixture control, inside of the cycle of 6 hours studied. In the study of the application of the method of the maturity, also we can verify the influence of the RHA in the analyzed mixtures:

- *We can observe in Figures 3 and 4 that the curves that represent the maturity index for the concrete possess next values of tension only in an initial interval; however the values for the mixture control (CC) assume they're from bigger values until the end of the curve;*
- *In the index of maturity, expressed in terms of the factor of maturity (Figure 3), the curves that represent the traces with RHA addition approximately possess the same value of tension throughout the entire curve;*

- *The same happens when we express this index in terms of age, equivalent 80°C (Figure 4), being the still more next values of tension that in the previous case, for the curves of the mixtures with RHA;*
- *As displayed above, the variation of the RHA dosage in the mixture did not modify the results of the maturity index, in the both cases;*
- *The introduction of the RHA had probable influence in the tax of cement hydration, modifying the times of the pozzolans reactions, differentiating the mixtures how much to its index of maturity that is a proper characteristic of each cimenticious mixture.*

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