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Strength development of concrete with rice-husk ash

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Abstract

This paper presents a study on the development of compressive strength up to 91 days of concretes with rice-husk ash (RHA), in which residual RHA from a rice paddy milling industry in Uruguay and RHA produced by controlled incineration from the USA were used for comparison. Two different replacement percentages of cement by RHA, 10% and 20%, and three different water/cementicious material ratios (0.50, 0.40 and 0.32), were used. The results are compared with those of the concrete without RHA, with splitting tensile strength and air permeability. It is concluded that residual RHA provides a positive effect on the compressive strength at early ages, but the long term behavior of the concretes with RHA produced by controlled incineration was more significant. Results of splitting tensile and air permeability reveal the significance of the filler and pozzolanic effect for the concretes with residual RHA and RHA produced by controlled incineration.

Keywords: Rice-husk ash; Pozzolans; Strength; High-strength concrete

1. Introduction

In Uruguay, rice production has had a dramatic increase over the past 10 years, becoming the most important crop since 2001; the main use of rice husk is as fuel in the rice paddy milling process. The use of this fuel generates a huge volume of ash. The rice-husk ash (RHA) has no useful application, is usually dumped into water streams and causes pollution and contamination of springs. As a result, the use of rice-husk ash has aroused great interest in Uruguay.

Rice-husk ash is a mineral admixture for concrete [1,2]; the behavior of cementitious products varies with the source of RHA [3,4]. The basic aim of this study is to investigate the influence of residual RHA from the rice paddy milling industry in Uruguay and RHA produced by controlled incineration from the United States, used for comparison, on strength development of concretes at different ages.

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2. Experimental program

The following materials were used in the preparation of the concrete specimens: fine aggregate (local natural sand) with maximum aggregate size of 4.75 mm; coarse aggregate (crushed granite) with maximum aggregate size of 12.5 mm; Portland Cement type I (normal portland cement); and superplasticizer based on a sulfonated naphthalene formaldehyde condensate. Two sources of ash were considered; a residual RHA from the unique rice paddy milling industry in Uruguay (UY RHA) and a homogeneous ash produced by controlled incineration from the United States (USA RHA), for comparison.

The residual RHA used for this work was a processed waste dry-milled for the necessary time to obtain a median particle size of 8 μm, a defined specific surface by nitrogen adsorption [5], and with the maximum activity index according to the ASTM C311-98b. This procedure of optimization is presented in [6]. Table 1 shows the chemical composition, physical properties and activity index of the cementitious materials.

Chemical analysis indicate that the two ashes are mainly composed of SiO_2. The median particle size of the two

Table 1
Physical properties and chemical analyses of the cement and RHA used

	Cement	RHA	
		UY	USA
Physical tests			
Specific gravity	3.14	2.06	2.16
Fineness			
Specific surface, Blaine, m^2/kg	309	–	–
Nitrogen adsorption, m^2/kg	–	28,800	24,300
Setting time, min			
Initial	145	–	–
Final	275	–	–
Compressive strength, Mpa			
1-day	10.1	–	–
3-day	22.8	–	–
7-day	33.1		–
28-day	45.1		–
Chemical Analyses, %			
Silicon dioxide (SiO_2)	21.98	87.2	88
Aluminium oxide (Al_2O_3)	4.65	0.15	–
Ferric oxide (Fe_2O_3)	2.27	0.16	0.1
Calcium oxide (CaO)	61.55	0.55	0.8
Magnesium oxide (MgO)	4.27	0.35	0.2
Manganese oxide (MnO)	–	–	0.2
Sodium oxide (Na_2O)	0.11	1.12	0.7
Potassium oxide (K_2O)	1.04	3.60	2.2
Sulphur oxide (SO_3)	2.19	0.32	–
Loss on ignition	2.30	6.55	8.1
Compounds			
Tricalcium silicate C_3S	44.0	–	–
Dicalcium silicate C_2S	29.9	–	–
Tricalcium aluminate C_3A	8.5	–	–
Tetracalcium aluminoferrite C_4AF	6.9	–	–
Activity index			
ASTM C311-98b	100	92.93	92.4

ashes is the same, and the activity index are similar. X-ray diffraction analysis indicated that the USA RHA can be considered to be non-crystalline RHA; but the UY RHA showed crystalline materials, which were identified as cristobalite. A rapid analytical method to evaluate amorphous silica in the rice husk ashes according to [7] has been used; the percentage of reactive silica contained in the USA RHA was 98.5% and in the UY RHA was 39.55%.

A total of 15 concrete mixes were made; for each RHA, six concrete mixes were made, and three concretes without RHA for comparison.The different mix proportions by mass of the materials used are given in Table 2. The replacement of cement by RHA was made by volume, because the RHA presents less specific gravity than the cement Portland, and the paste content in volume was kept the same (35% cement paste content) for the different mix proportions. The values of the slump test are also indicated in Table 2, where superplasticizer percentages are used in relation to weight of cementitious materials. Superplasticizer was used in very low percentages according to the results obtained in the slumps, to allow consistency adjustments (slump $= 60 \pm 20$ mm) without changing the proportion of the other materials.

Cylindrical concrete test specimens were cast. They were compacted by external vibration and kept protected after casting to avoid water evaporation. After 24 h they were demolded and stored in a moist room until the testing date.

100×200-mm cylinders were used to observe the compressive strength at 7, 28 and 91 days. In order to obtain more information about the development of strength of the concretes, splitting tensile tests and air permeability on cylinders of 100×200 mm and 150×300 mm respectively, with lower and higher water/cementitious materials ratios at the age of 28 days, were analysed. Air-permeability for concrete was determined with the "Torrent permeability tester" method [8,9]. The particular features of the Torrent method are a two-chamber vacuum cell and a pressure regulator, which ensures that air flows at right angles to the surface and is directed towards the inner chamber; this allows the calculation of the permeability coefficient K_t on the basis of a simple theoretical model. By comparing the results [9] of gas permeability measured by the Torrent permeability tester (K_t) and oxygen permeability obtained for the Cembureau method (K_0), the following relation is presented: $K_0 = 2.5\ K_t^{0.7}$ where K_0 and K_t are expressed in 10^{-16} m^2.

3. Results and discussion

Table 3 shows the test results (strength and permeability). Each value represents the average of five experimental observations. At lower ages (7 days), concretes with UY

Table 2
Mix proportions of concrete

W/(c + RHA)	RHA (%)	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Superplast (%)		Slump (mm)	
					UY	USA	UY	USA
0.32	0	534	690	1050	0.40		47	
	10	481	690	1050	0.20	0.70	45	56
	20	427	690	1050	0.20	0.80	48	63
0.40	0	462	723	1018	0.10		40	
	10	416	723	1018	0.20	0.27	40	56
	20	370	723	1018	0.40	0.50	53	65
0.50	0	408	758	983	–		61	
	10	367	758	983	–	0.30	94	79
	20	327	758	983	–	0.40	67	53

Table 3
Test results

w/(c + RHA)	RHA		f_c (MPa)			$f_{t,d}$ (MPa) 28d	K_t (m^2) 28d
	Type	%	7d	28d	91d		
0.32		0	48.4	55.5	60.6	3.63	1.08×10^{-16}
	UY	10	51.1	60.4	64.3	3.57	0.23×10^{-16}
		20	44.3	54.8	62.7	3.34	0.05×10^{-16}
	USA	10	39.5	51.4	64.5	3.62	0.08×10^{-16}
		20	30.5	47.4	68.5	3.54	0.03×10^{-16}
0.40		0	35.8	42.3	45.6		
	UY	10	41.1	50.4	54.9		
		20	27.9	40.7	51.4		
	USA	10	29.7	40.8	51.5		
		20	23.6	39.4	57.3		
0.50		0	24.6	32.9	35.9	2.85	28.20×10^{-16}
	UY	10	24.1	31.5	35.5	2.32	71.82×10^{-16}
		20	24.9	34.9	37.9	2.63	49.10×10^{-16}
	USA	10	22.7	34.5	44.4	2.92	26.36×10^{-16}
		20	20.8	35.9	52.9	3.00	14.20×10^{-16}

Keys: f_c = axial compressive strength; $f_{t,d}$ = splitting tensile strength; K_t = permeability coefficient.

RHA present higher compressive strength that concretes with USA RHA. At higher ages (91 days), the RHA concrete had higher compressive strength in comparison with that of concrete without RHA, and the highest values of compressive strengths were achieved in concretes with 20% USA RHA. The long term compressive strength of the concretes with UY RHA is not as high as the one obtained with USA RHA, which also increases as the RHA content rises.

The results of splitting tensile strength and air permeability reveal the significance of the filler and pozzolanic effect for the concretes with RHA. On the one hand, the results are consistent with the compressive strength development at 28 days for the USA RHA. On the other hand, in the concretes with UY RHA, lower splitting tensile strengths and less air permeability are observed, which can be due to the fact that with residual RHA, the filler effect of the smaller particles in the mixture is higher than the pozzolanic effect.

4. Conclusions

The RHA concrete had higher compressive strength at 91 days in comparison with that of the concrete without RHA, although at 7 and 28 days a different behavior was observed between the concretes with the two RHA considered.

The increase in compressive strength of concretes with residual RHA is better justified by the filler effect (physical) than by the pozzolanic effect (chemical/physical). The increase in compressive strength of concretes with RHA produced by controlled incineration is mainly due to the pozzolanic effect.

It is concluded that residual RHA provides a positive effect on the compressive strength of concretes at early ages, but in the long term, the behavior of the concretes with RHA produced by controlled incineration was more significant.

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