PORTUGUESE RICE HUSK ASH AS A PARTIAL CEMENT REPLACEMENT

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ABSTRACT

This paper presents a study of Portuguese rice husk ash as a partial cement replacement, in different percentages.
Portuguese rice husk is a by-product which may be incinerated industrially.
Various tests were carried out to evaluate durability of concrete made with 10, 15 and 20% replacement of rice husk ash by weight of cement.
Tests carried out and reported in this paper concern strength, absorption by capillarity and chloride ion penetration.
All results lead to the conclusion that Portuguese rice husk ash is highly recommended to enhance concrete performance.

Keywords: rice husk ash, concrete durability, partial cement replacement, chloride resistance, testing.

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INTRODUCTION

During the 20th century there has been an increase in the consumption of mineral admixtures by the cement and concrete industries. This rate is expected to increase. The increasing demand for cement and concrete is met by partial cement replacement. Substantial energy and cost savings can result when industrial by-products are used as a partial replacement for the energy/intensive Portland cement. The presence of mineral admixtures in concrete is known to impart significant improvements in workability and durability. The use of by-products is an environmental-friendly method of disposal of large quantities of materials that would otherwise pollute land, water and air. The current cement production rate of the world, which is approximately 1.2 billion tons/year, is expected to grow exponentially to about 3.5 billion tons/year by 2015. Most of the increase in cement demand will be met by the use of supplementary cementing materials, as each ton of Portland cement Clinker production is associated with a similar amount of CO_2 emission [1].

Rice husks, an agricultural waste, constitute about one fifth of 300 million tons of rice produced annually in the world. By burning the rice husks under a controlled temperature and atmosphere, a highly reactive rice ash is obtained [2,3].

In fact the ash consists of non-crystalline silica and produces similar effects in concrete as silica fume. However, unlike silica fume, the particles of rice husks ash process a cellular structure – Figure 1, which is responsible for the high surface area of the material even when the particles are not very small in size [1].

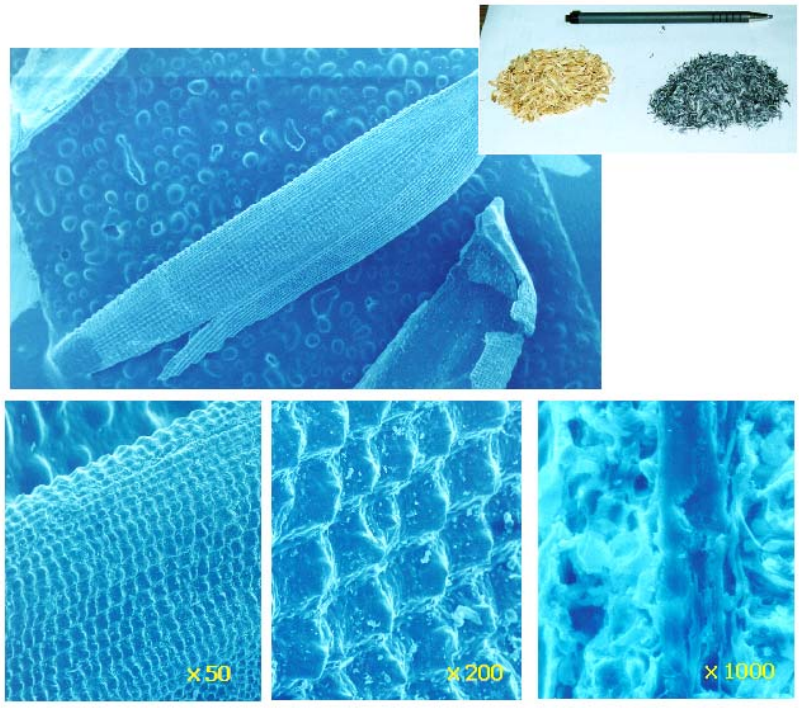


Figure 1 - Portuguese rice husks - cellular structure responsible for the high surface area.

The research programme, partially described in this paper, was carried out to assess performance of concrete obtained with partial cement replacements with Portuguese rice

husk ash in different percentages. The first part of the research programme involved testing concrete strength, absorption by capillarity and chloride ion resistance. The second part, to be published, concerns other tests such as permeability (water penetration under pressure) and carbonation resistance. Results of the tests obtained for concrete with 10,15 and 20% cement replacement with rice husk ash were compared with control concrete (0% cement replacement) and also with a second control concrete made with 10% cement replacement with silica fume, a pozzolan with well known properties for enhancing concrete durability.

A thermal analysis (TG-DTA) was initially undertaken on a sample of rice husk and the graph in Figure 2 was obtained, thus confirming the furnace temperature of approximately 650^{o}C to obtain amorphous silica.

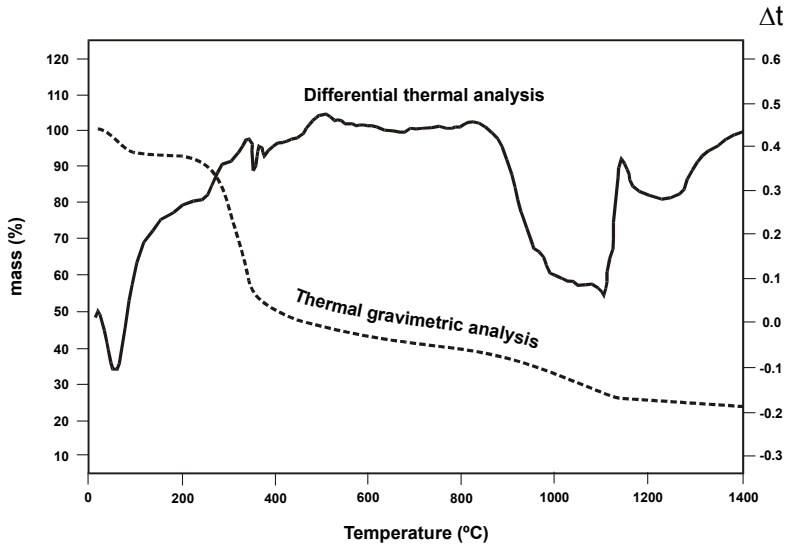


Figure 2 – Thermal analysis curves for Portuguese rice husk.

Portuguese rice husk – Figure 3, was then incinerated in an oven at heating rate of 10^{o}C per minute up to 650^{o}C, maintained at this temperature for 8 hours, and then allowed to cool down to room temperature – Figure 4. The ash was then grinded. Figure 5 shows its particle size distribution.

Figure 3 – Raw rice husk.

Figure 4 – Rice husk ash.

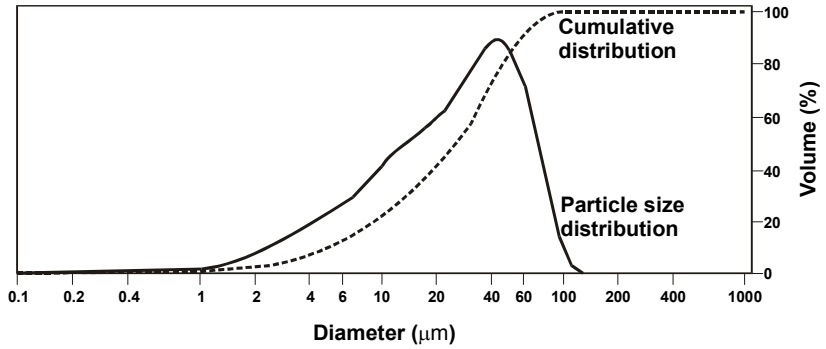
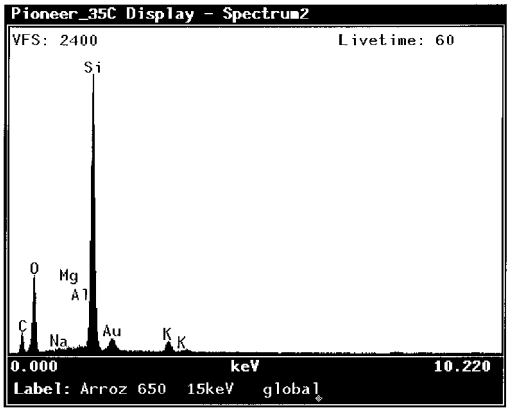


Figure 5 – Particle size distribution of the rice husk ash.

Electron Scanning Microscopy testing was undertaken on samples of rice husk ash and a qualitative chemical analysis is given in Figure 6.



Compound Formula	Normalized Compound %
Al_2O_3	0.40
SiO_2	93.36
K_2O	5.22
Na_2O	0.62
MgO	0.40

Figure 6 – Qualitative chemical analysis of rice husk ash.

The specific gravity of the ash was also evaluated and a value of 2.15 g/cm^3 was obtained. The BET surface area was 22,36 m^2/g and the XR diffraction pattern confirmed that rice husk ash is mainly amorphous silica -Figure 7.

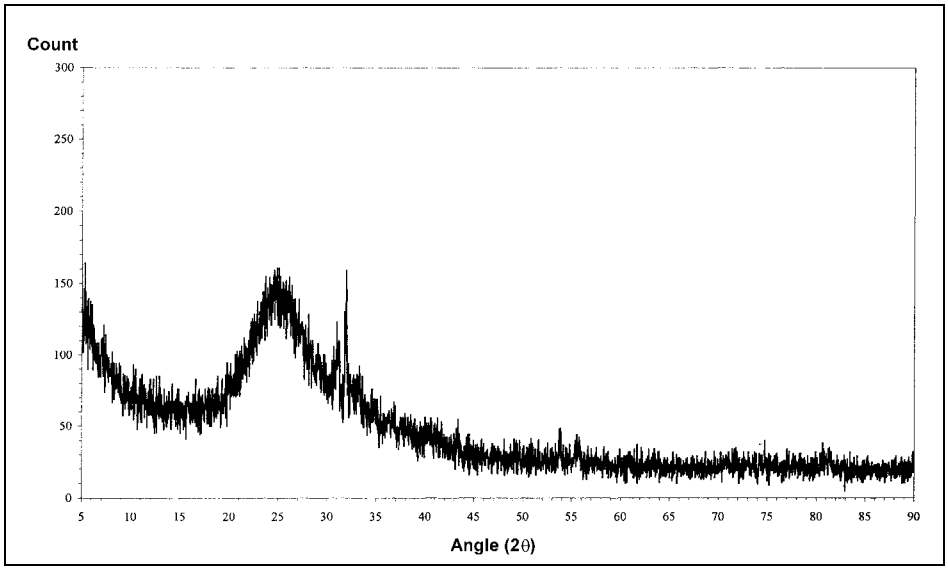


Figure 7 - XR diffraction of rice husk ash.

Materials and concrete mixes

A concrete specimen of approximately 30 x 20 x 80 cm was cast for each mix considering a control mix, three mixes corresponding to 10%, 15% and 20% rice husk ash cement replacement, and another mix corresponding to 10% silica fume cement replacement. Mixture proportions are given in Table 1. Symbols used to identify each mix are CTL for the control mix, 10% RHA (or 1A) for 10% cement replacement of rice husk ash, 15% RHA (or 1A5) for 15% replacement of rice husk ash, 20% RHA (or 2A) for 20% replacement (20% RHA) and SF for 10% cement replacement with silica fume.

Table 1 –Concrete mixture proportions.

Mixture Proportions		Control	Partial cement replacement of			
		CTL	10% RHA	15% RHA	20%RHA	10% SF
cement	kg/m^3	354	321	303	283	320
silica fume	kg/m^3	-	-	-	-	35
rice husk ash	kg/m^3	-	35	53	72	-
fine sand	kg/m^3	151	152	152	153	152
coarse sand	kg/m^3	739	743	745	746	742
coarse agg. 5/15	kg/m^3	436	438	439	440	438
coarse agg.15/25	kg/m^3	568	571	572	574	571
superplasticizer	%/B	1,2%	1,2%	1.2%	1.2%	1.2%
water (w)	l/m^3	151	152	152	153	152
water/binder	w/B	0.43	0.43	0.43	0.43	0.43
slump	mm	145	15	20	20	35

Cement used was CEM type II 32.5 in accordance with the European Standards. Silica fume used is commercially available and its specific gravity is 2.2 g/cm^3. Portuguese rice husk ash was obtained in the laboratory as explained earlier. The superplasticizer used was Sikament, produced by Sika. Fine and coarse sand are of natural origin and coarse aggregates 5/15 and 15/25 are locally obtained, all of granitic origin. The particle size distributions are shown in Figure 8.

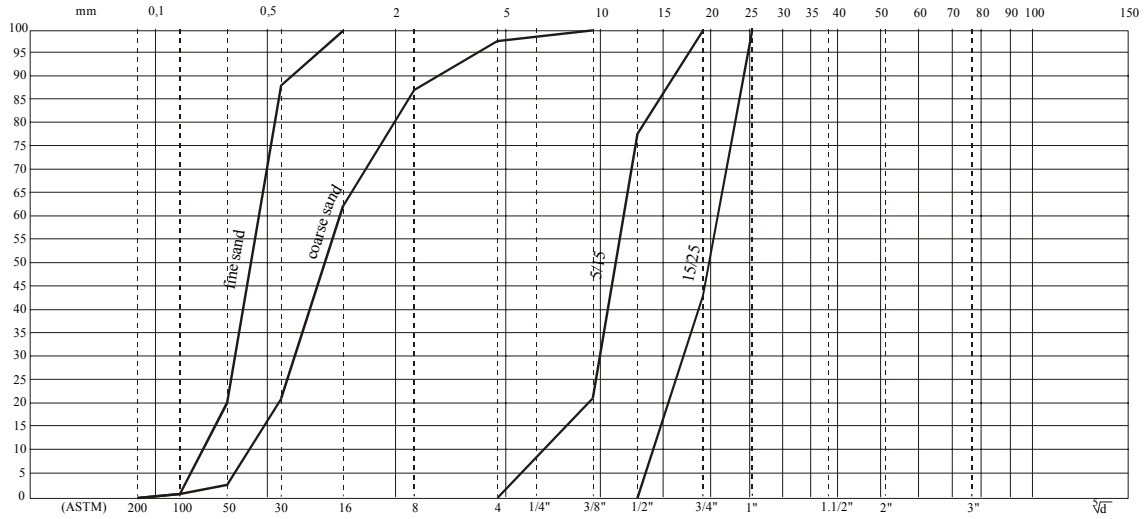


Figure 8 – Particle size distribution of fine and coarse aggregates used.

Concrete was produced for each mix, the slump was measured (Table 1) and each mould was filled with successive layers and vibrated with a suitable poker. The top face was then

covered with plastic and the formwork was stripped off 30 hours later and cured for a further five days at room temperature (20°C).

Later cores from each test specimen were drilled out according to the location shown in, Figure 9 and were submerged in water until time for testing.

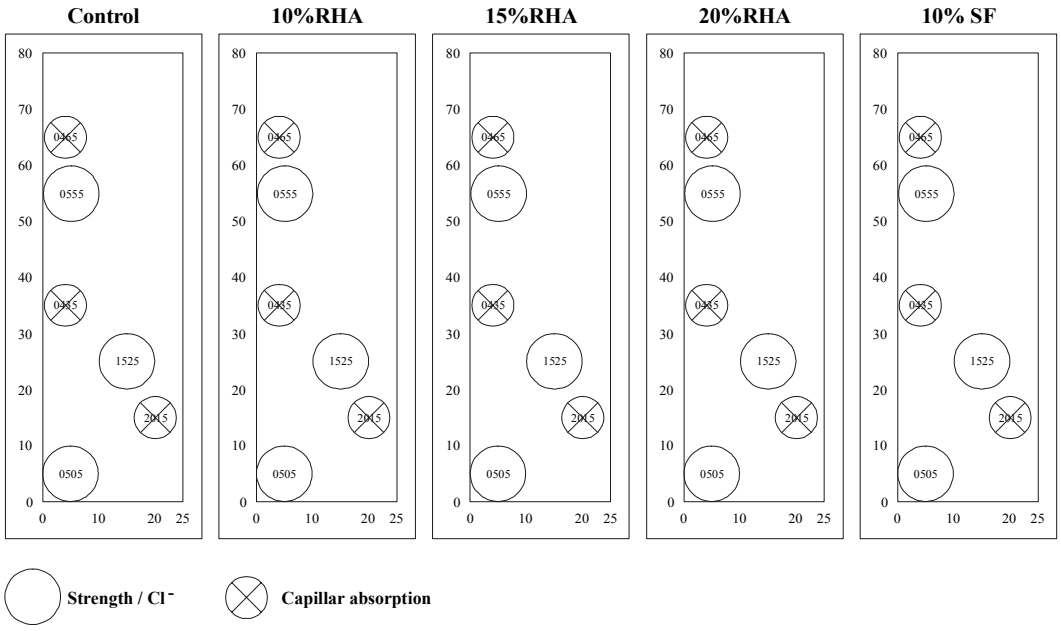


Figure 9 – Location of test-cores.

Testing

Test results reported in this paper concern strength at 80 days, absorption by capillarity and chloride resistance.

Strength

Strength testing was undertaken at 80 days, on cores of 94 mm diameter and approximately 100 mm length. These were obtained from the test cores of approximately 200 mm length, located as shown in Figure 9, by sawing off the two top 50 mm length discs to be used for chloride resistance testing. Results are shown in Table 2 and Figure 10.

Table 2 – Strength at 80 days (MPa)

Location		0505	1525	0555	Average
Control	CTL	36.2	35.4	33.7	35.1
Silica fume	SF	39.4	38.6	38.1	38.7
10% RHA	1A	41.0	42.3	41.2	41.5
15% RHA	1A5	40.7	44.3	40.1	41.7
20% RHA	2A5	42.6	42.7	43.7	43.0

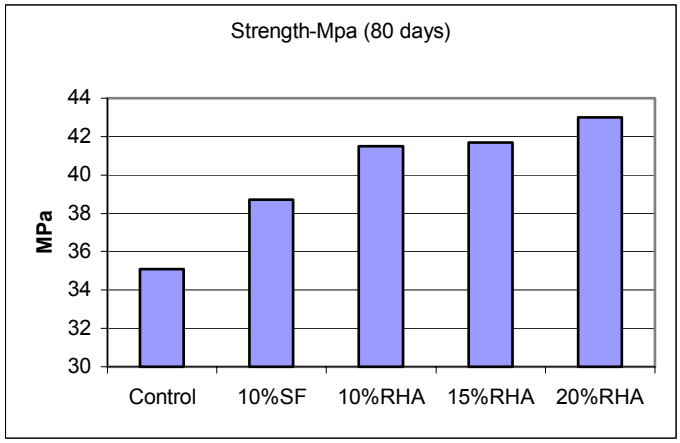


Figure 10 – Average strength.

Absorption by capillarity

These tests were undertaken on 105 days old cores, approximately 74 mm diameter by 100 mm length corresponding to half a core drilled out as located in Figure 9. Test cores were previously prepared with a 10 mm wide ring of epoxy resin applied to the round surface next to the formwork face so that water would only be absorbed through this face. Then they were put to dry in a ventilated heater at 40°C until constant mass. For the test itself, cores were placed formwork face downwards, in a shallow water bath and supported on rods. Water level was adjusted so that the formwork face was dipped to a depth of approximately 3 mm. During the test, water was drawn into the core, only through the formwork face, by capillary forces and weighed at time intervals up to 4 hours from the start of the test.

The absorption of water into concrete under capillary action is dependent on the square-root of time [4] and may be modelled by the following equation:

$$A = a_o + St^{0,5} \quad (1)$$

Where A (mg/mm^2) is the water absorption by unit area of concrete surface since the moment the core was dipped in water, S is the sorptivity of the material, t is the elapsed time and a_o (mg/mm^2) is the water absorbed initially by pores in contact with water. The above equation was found to provide a very good fit to the data with coefficients of correlation over 0.992.

For each group of three test-cores corresponding to a different mix, the average absorption by capillarity was calculated and is shown in Figure 11. Sorptivity values, S, are shown in Table 3 and Figure 12.

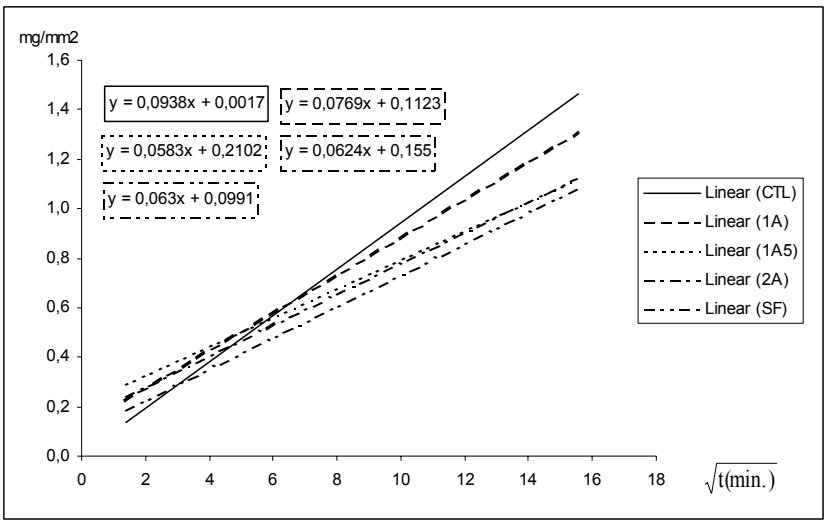


Figure 11 – Average absorption versus time, for each mix.

Table 3 – Sorptivity values at 105 days-S ($mg/mm^2 \times min.^{1/2}$)

Location		2015	0435	0465	Average
Control CTL	CTL	0.0936	0.0927	0.0951	0.094
Silica fume	SF	0.0608	0.0686	0.0596	0.063
10% RHA	1A	0.0689	0.0694	0.0925	0.077
15% RHA	1A5	0.0666	0.0567	0.0517	0.058
20% RHA	2A5	0.0696	0.0592	0.0584	0.062

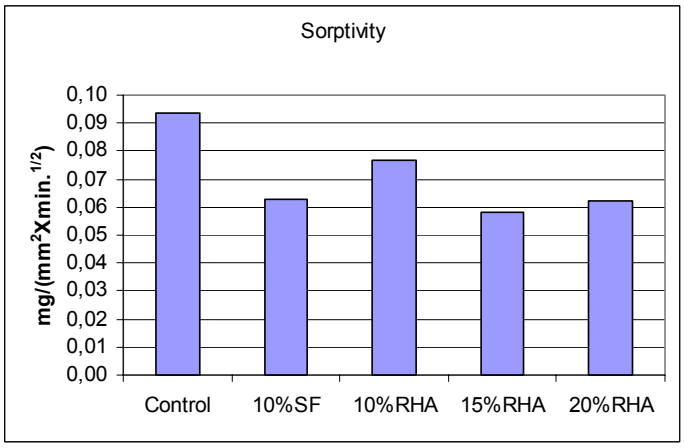


Figure 12 – Average sorptivity values for each mix.

Resistance to chloride penetration

Resistance to chloride penetration may be assessed with the AASHTO T277 – 83 test method, "Rapid Determination of the Chloride Permeability of Concrete" and it is the most commonly accepted test in North America. Briefly, the above method consists of monitoring the amount of electrical current passed through an approximately 100 mm diameter by 50 mm thick concrete specimen, when a potential difference of 60V is maintained across the specimen for a period of six hours. Chloride ions are forced to migrate out of a NaCl solution subjected to a negative charge through the concrete into a NaOH solution maintained at a positive potential – Figure 13.

The conditioning of the concrete disc specimens for the test procedure consists of one hour of air drying, three hours of vacuum (pressure <1 mm Hg), one hour of additional vacuum with specimens under deaerated water, followed by 18 hours of soaking in water. The total charge passed, in coulombs, is used as an indicator of the resistance of the concrete to the passage of chloride ions [5].

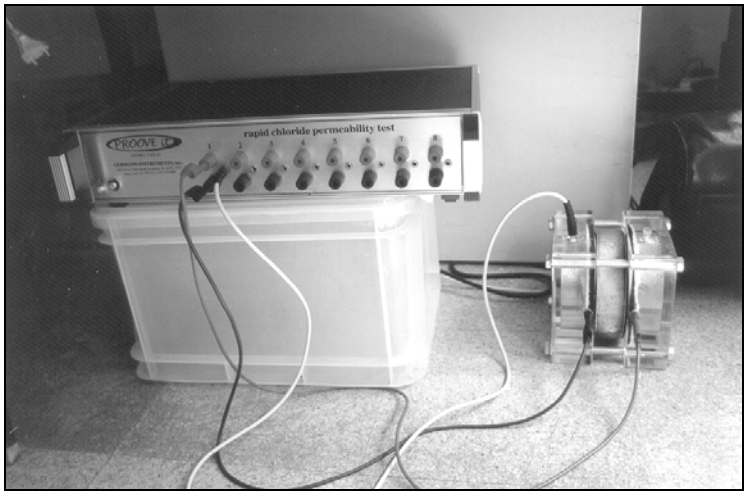


Figure 13 – Rapid determination of chloride permeability of concrete.

Results of this test carried out between 90 and 100 days, are shown in Table 4 and Figure 14.

Table 4 – AASTHO test results at 90-100 days (Coulombs).

Location		2015	0435	0465	Average
Control	CTL	2285	2565	2198	2349.3
Silica fume	SF	461	439	493	464.3
10% RHA	1A	376	471	458	435.0
15% RHA	1A5	345	329	292	322.0
20% RHA	2A	258	291	230	260.0

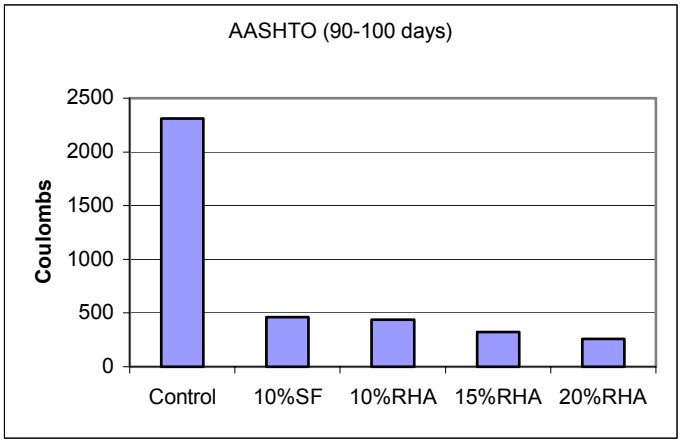


Figure 14 - Average AASTHO test results.

CTH Rapid Method:

The AASTHO test method although an important contribution as a simple and quick method, has been subject to some criticism [6,7] and other tests have been idealized, including the CTH Rapid Method.

The CTH Rapid Method is a non-steady state migration method based on a theoretical relationship between diffusion and migration which enables the calculation of the chloride diffusion coefficient from an accelerated test [8]. It is based in measuring the depth of colour change of a silver nitrate solution sprayed on specimens previously submitted to a migration test and application of the following equations [8,9]:

$$D_{ns} = \frac{RTL}{ZFU} \frac{x_d - \alpha\sqrt{x_d}}{t} \quad (2)$$

$$\alpha = 2\sqrt{\frac{RTL}{ZFU}}.\varepsilon \quad \varepsilon = \text{erf}^{-1}(1 - \frac{2C_d}{C_o}) \quad (3)$$

Where:
D_{ns} – Apparent diffusion coefficient obtained in a non-steady state migration test (cm^2/s)
R – Gas constant R = 8.314 J/(mol.K)
T – Absolute temperature (K)
L – Thickness of specimen (cm)
Z – Ion valence
F – Faraday constant, F = 9.648×10^4 J (V.mol.)
U – effective voltage applied (V)
x_d – Depth of chloride penetration measured by using a colorimetric method (cm)
t – Time of test duration (s)
α - Laboratory constant
ε = 0 0.764 if external chloride concentration of 0,5 M.
C_d – Concentration of free chloride at which the colour changes when using the colorimetric method to measure the chloride penetration depth ($kg_{Cl}/m^3_{solution}$)
C_o – Concentration of free chloride in the external solution.

The procedure for determining the Apparent Diffusion Coefficient (D_{ns}) consisted of after switching off the electrical field, the specimens were split in two halves and the penetration of chlorides was measured by using the colorimetric method. This method consists of spraying silver nitrate solution over the split faces, storing them in a dark place for an hour and then exposing them under a fluorescent light for a few hours (Figure 15), after which the average front of the white zone in the central part of each specimen is measured with a precision of 0.5 mm [8].

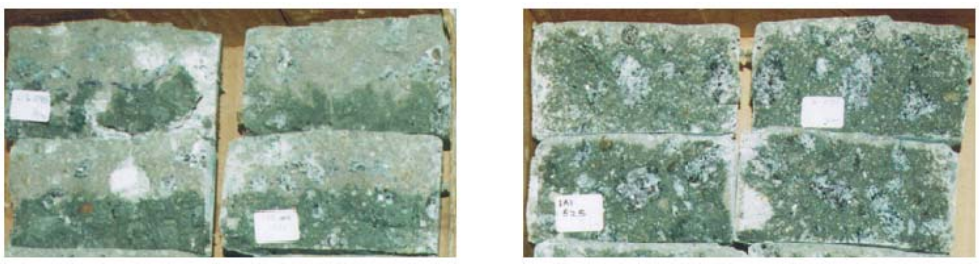


Figure 15 - Depth of chloride penetration ascertained by the colorimetric method after a migration test in test-cores of the CTL concrete, on the left, and 10% RHA, on the right.

D_{ns} results are shown in Table 5 and Figure 16.

Table 5 – Apparent diffusion coefficients D_{ns} (cm^2/s)

Location		2015	0435	0465	Average
Control	CTL	29.5×10^{-8}	23.7×10^{-8}	23.7×10^{-8}	25.6×10^{-8}
Silica fume	SF	$5{,}4 \times 10^{-8}$	4.5×10^{-8}	7.3×10^{-8}	5.7×10^{-8}
10% RHA	1A	$5{,}4 \times 10^{-8}$	3.1×10^{-8}	3.5×10^{-8}	4.0×10^{-8}
15% RHA	1A5	$3{,}5 \times 10^{-8}$	0.8×10^{-8}	5.4×10^{-8}	3.2×10^{-8}
20% RHA	2A	$3{,}1 \times 10^{-8}$	1.2×10^{-8}	1.7×10^{-8}	2.0×10^{-8}

DISCUSSION AND CONCLUSION

Considering the parameters analysed earlier, it is obvious that concrete with 10%, 15% and 20% cement replacement by Portuguese rice husk ash performs better than control concrete, this is, concrete with no cement replacement – Table 6. In fact, the performance of concrete with cement replacement by ash is outstanding considering resistance to chloride ion penetration which is in many cases the most important characteristic concerning durability and corrosion prevention. The rice husk ash concrete seems to perform also better than silica fume concrete, at least concerning strength and chloride resistance, but these results need to be completed with more data dealing with other parameters currently being analysed such as carbonation and permeability.

Table 6 - Comparison of results concerning rice husk ash concrete and control concrete.

	Improvement related to control concrete (0% RHA)			
	Strength	Sorptivity	Chloride Resistance	
			AASHTO test	D_{ns}
10% RHA	18%	18%	81%	84%
15% RHA	19%	38%	86%	84%
20% RHA	23%	33%	89%	92%

ACKNOWLEDGEMENTS

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