Influence of Exposure Conditions on the Values of Strength and Absorption in the Soil Stabilized with Lime and Rice Husk Ash

M.A.M. Alcantara, L.L. Fernandes, J.A. Lollo, D.C. Lima

Abstract. The article presents a study on the influence of exposure conditions on strength and absorption in soil stabilized with lime and rice husk ash. A soil classified as A-4 and CL, known as Red-Yellow Podzol, a hydrated lime and a crystal-type burnt rice husk ashes were used throughout the study. The laboratory testing program encompassed compaction of specimens of soil and its mixtures with lime content of 8% enriched with ash contents of 5% and 10% of the soil dry weight in the Normal Proctor Energy. The specimens were moist-cured for 28 days and then subjected to different exposure conditions, including curing in kiln oven, fully exposed and immersed in water. After curing the specimens were subjected to compressive strength tests with and without previous 24 h immersion in water, and also to absorption tests. Results showed the advantages of using ash as an auxiliary additive in soil-lime mixtures to promote mechanical strength increase and its long-term maintenance, as well as reducing the influence of saturation on compressive strength. Water immersion promoted the best mechanical strength increase, and water absorption increased with the increasing percentage of ash and with the curing time of the mixtures.

Keywords: stabilized soil, soil-lime, soli-lime-ash, mechanical strength, water absorption, soil mixtures cure.

1. Introduction

Of the stabilization mechanisms in the soil-lime mixtures, the pozzolanic reactions stand out among the solubilized mineral elements of soil and lime,which normally result in increased soil mechanical strength. According to Alcântara (1995), the addition of pozzolans can improve the stabilization effectiveness of soils with lime. Sharma *et al.* (2012) present chaos were the UCS value increased to 105 kPa and the CBR value increased to 5,7% by addition of 20% ash and 8,5% of lime. Still according Saeid *et al.* (2012) the additions could improve the mechanical properties of soils such as strength, swelling, plasticity index and compressibility; and, the obtained results indicated that for a progressing in soil properties the combination of lime and ash might be more effective than use of only lime or ash.

Among these there is rice husk ash, which according to chemical and mineral analysis, present a high silica content as mineral element after firing, which may be in amorphous or crystalline forms. The pozzolanic activity of rice husk ash can be seen in Cincotto & Kaupatez (1984), Barbosa (2006), Silva (2009) and Alcântara *et al.* (2010). Within this context, experiments were conducted using rice husk ash as an additive for soil stabilization, together with lime. According to Alcântara *et al.* (2010), the addition of 5% and 10% of crystalline rice husk ash to a A-4 soil (Red-Yellow Argisol), stabilized with 8% hydrated lime and compacted in the normal Proctor test energy, produced compressive strength gains of 16.6% and 57%, respectively, at 90 days of curing.

Thus, with the aforementioned technological aspects, the importance of this type of materials for engineering solutions is taken into account, with the durability aspect comprising an important aspect for the reliability of such materials. Alcântara *et al.* (2011) report results of a study that produced soil-lime-ash bricks using crystalline rice husk in a hand press, compressed to approximately 95% of maximum dry specific weight as determined by Alcântara *et al.* (2010), according to NBR 10832 (ABNT, 1989). This study obtained higher mechanical strength values of 3.6 MPa and 3.4 MPa, for 90 days of curing in a humid chamber and in a kiln oven, respectively, because the minimum required by NBR 8491 (ABNT, 1984a), and NBR 8492 (ABNT, 1984b) is of 2 MPa. However, these authors reported that the mechanical strength values of the bricks experienced a gradual decrease when considering curing times of 28 to 90 days, observing a decrease in strength of about 13% and 25% for humid chamber curing and kiln oven curing, respectively. On the other hand, the absorption values increased by 4% for humid chamber curing and 1% for kiln oven curing. In experiments conducted by Akasaki & Silva (2001) and Milani (2005), it was reported that when

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using rice husk soil-cement-ash, and with the same degree of compaction, there was a mechanical strength decrease and increased absorption in stressed conditions, with the lowest degree of compression as the cause for the increased water absorption.

The ensuing actions of changing exposure conditions, resulting in different absorption and drying and expansion and contraction cycles, due to temperature variations throughout the day, such as weathering agents, which influence soil durability stabilized with lime, and which can be influenced by the degree of compression are discussed in Alcântara *et al.* (1996). However, Alcântara *et al.* (2011) draw attention to the presence of ash in the absorption processes and discuss the rupture test procedure, when the material is immersed prior to the test, and which may interfere in the mechanical strength values due to water absorption resulting from its hygroscopic and porosity nature and also its internal permeability condition, which can be another microcracking indicator.

2. Materials and Methods

This study verifies the durability of engineering parameters of specimens of soil and soil-lime-rice husk ash mixtures compacted in the mini-Proctor test. The work of Alcântara *et al.* (2010) was used as a basis in the production of the specimens for the soil and mixes, using optimum compaction parameters determined in the compaction energy of the standard Proctor test, according to NBR 7182 (ABNT, 1986), using a lime content of 8% and calcined and ground crystalline rice husk ash contents of 5% and 10%, in relation to the dry soil weight.

The grinding and characterization of rice husk ash were performed in the Civil Engineering CESP Laboratory of Ilha Solteira, using the equipment of the Civil Engineering Laboratory of Ilha Solteira - UNESP for the production, curing, mechanical resistance and absorption tests of the specimens of soil and mixtures.

In order to check the durability of the soil-lime-ash mixture with different exposure conditions, samples with ash contents of 5% and 10% were prepared based on the results by Alcântara *et al.* (2010). Besides the soil-lime-ash sample specimens, soil samples and their mixture with 8% of hydrated lime were prepared, and these results were used as the comparative performance basis for the soil-lime-ash mixtures.

2.1. Materials

The crystalline rice husk ash used in the tests was from the region of Pelotas, Rio Grande do Sul, Brazil, which was ground in a ball mill for 30 minutes, similar to that used for cement production in the Civil Engineering CESP Laboratory of Ilha Solteira. Figures 1 and 2 show the aspect of the ground ash, ready to use and sieved, and Table 1 shows the data of the physical and chemical characteristics of this material.

In the experiment, the water supply of the city of Ilha Solteira, São Paulo, Brazil was used, and in the mixtures CH-III-type hydrated lime was used, with physical, chemi-

Table 1 - Physico-chemical characteristics of crystalline rice husk ash.

Sample		Crystalline Rice Husk Ash	NBR-12653 (Pozzolanic material)	
			Min	Max
Apparent density (kN/m^3)		6.0	-	-
Absolute density (kN/m^3)		21.4	-	-
Grain diameter (micra)		20.13	-	-
Moisture of sample (%)		1.08	-	3.0
Chemical analysis (%)	Fire loss	7.95	-	6.0
	SiO_2		-	-
	Fe_2O_3		-	-
	Al_2O_3		-	-
	CaO		-	-
	MgO		-	-
	SO_3		-	5.0
	Al_2O_3+Fe_2O_3		-	-
	SiO_2+Al_2O_3+Fe_2O_3		70.0	-
	Equiv. Alc. in Na_2O (disp.)		-	-
	Na_2O		-	-
	K_2O		-	-

Figure 1 - Ground rice husk ash.

Figure 2 - Sieved soil.

cal and mechanical properties that met the requirements of NBR 7175 (ABNT, 1984c). The soil used was classified as A-4, according to the Transportation Research Board Soil Classification System - TRB (DNIT, 2006), as CL, according to the Unified Soil Classification - USC (DNIT, 2006) and as Red-Yellow Argisol, according to the pedological classification (EMBRAPA, 2006). Figure 2 shows the aspect of the soil collected after sieving, Table 2 shows the test characterization results and geotechnical classifications of the soil (Alcântara, 1995) and Table 3 shows the results of the compression test performed on the soil and on the soil-lime (8%), soil-lime (8%)-ash (5%) and soil-lime (8%)-ash (10%) mixtures.

The results obtained in the compression tests clearly show the optimum moisture content increase and the maximum dry density decrease in the following order: natural soil, soil-lime, soil-lime-ash (5%) and soil-lime-ash (10%). The DNER-ME 228-94 standard was followed for the production of the specimens. All test specimens were first cured packed in plastic bags and placed in a moist chamber for 28 days, and for 1/3 of them the last curing was performed in a kiln oven, 1/3 were exposed to the external environment and 1/3 were cured by water immersion in the humid chamber.

Table 2 - Soil geotechnical characterization and geotechnical classification test results.

Parameters	Soil
Liquid limit (%)	26
Plasticity index (%)	10
Specific particle weight (kN/m^3)	27.4
Particle size:	
$\Phi < 0.005$ mm (%)	31
$0.005 \leq \Phi < 0.05$ mm (%)	12
$0.05 < \Phi \leq 0.48$ mm (%)	57
Soil classification:	
TRB	A-4
USC	CL

Table 3 - Residual mature soil compaction parameters: optimum moisture content ($W_{ót}$) and maximum dry weight (γ_{dmax}).

Materials	Wot (%)	γ_{max} (kN/m^3)
Soil	12.37	19.2
Soil + 8% lime	13.71	18.8
Soil + 8% lime + 5% ash	13.67	18.4
Soil + 8% lime + 10% ash	14.42	18.1

2.2. Methods

After collecting the soil sample in the borrow area, it was exposed to air near the Civil Engineering Laboratory of Ilha Solteira Engineering School - UNESP, to achieve hygroscopic equilibrium with the environment, after being sifted and stored in plastic bags.

To produce the four kind of test specimens, namely: soil (S), soil with 8% lime (S-8), soil with 8% lime and 5% rice husk ash (S-8-5) and soil with 8% lime and 10% ash (S-8-10), the following steps were followed: (i) separating the soil to produce the specimens of approximately 200 g; (ii) calculating the quantities of ash and lime to be added to the soil in relation to its hygroscopic equilibrium weight with the environment, and; (iii) mixing and homogenizing soil-lime and soil-lime-ash in a plastic bag to prevent loss of moisture to the environment. First, the soil was mixed with lime, then the ash was added, when applicable. These materials were homogenized, and then after mixing, the water was added with additional homogenization; and (iv) the amount of mixture to be placed in the mini-Proctor compression cylinder was calculated to mold the 50 mm (height) specimens, considering a permissible deviation of 1 mm, compression degree of 100% and permitted deviation of 1%. Any test specimen that did not meet the required compression degree or height characteristics was discarded.

Of the 72 test specimens produced with the required characteristics, 18 were prepared with soil without additions, 18 with soil mixture plus 8% lime, 18 with soil mixture with 8% lime and 5% ash, and 18 with soil mixture with 8% lime and 10% ash. After the test specimens were prepared, identified and packaged in plastic bags, they were kept in a moist chamber for 28 days, after which a part was cured under total exposure to air, another part in a kiln oven and another part cured under water immersion. Thus, after the first 28 days of curing, the test specimens were unpacked and submitted to the respective three curing modalities. Figures 3 and 4 illustrate the test specimens already packed and ready to be taken to the humid chamber and the test specimens stored in a moist chamber.

Figure 5 shows the test specimens that were kept under immersion and cured in a water tray.

The test specimens in the kiln oven were placed on a tray and wrapped in a plastic bag, at the Laboratory of the Civil Engineering School of Ilha Solteira, so as not to be exposed to the direct action of weathering, as illustrated in Fig. 6.

Figure 7 shows the test specimens under total exposure and placed on perforated trays to prevent water accumulation, and exposed to weathering action in the external courtyard of the Laboratory of the School of Civil Engineering of Ilha Solteira.

Next, after the exposure period under different curing conditions, the specimens underwent the unconfined compression and water absorption tests, according to NBR 8492 (ABNT, 1984). The compressive strength tests were carried out by immersion, as well as without immersion, in water for 24 h prior to failure; the procedure was performed on the test specimens of the mixtures subjected to all cure types, except those consisting only of soil, due to the great strength loss, which exhibited a high degree of cracks for the exposed curing, or breaking up for the immersed curing. Immersion was performed in a 24-h period, one day prior to the compressive strength test. This procedure was carried out to analyze the saturation influence on the strength of various types of mixing and curing modes.

Figure 3 - Test specimens already packed, ready to go to a moist chamber.

Figure 4 - Test specimens stored in a moist chamber.

Figure 5 - Test specimens immersed cured.

Figure 6 - Test specimens cured in a kiln oven.

Figure 7 - Fully exposed cured test specimens.

The water absorption tests were performed on all test specimens, except for those constituted only of soil due to the aforementioned reasons. The purpose of these tests was to relate the absorption increase to the higher internal cracking, causing a compressive strength drop in the test specimens. The absorption tests were conducted after the immersion of the specimens for a 24 h period in order to obtain the wet mass and then oven dried at 105 °C until constant weight to determine dry weight. The percentage difference between the dry and saturated masses corresponded to the total capacity value of water absorption, calculated on a dry basis.

3. Results

For the soil without additives, due to their damage effects, it was not possible to present the compressive strength and water absorption results of the soil specimens subjected to the immersed curing, the exposed curing and after water immersion for 24 h. Figure 8 shows the broken soil specimens.

Figure 9 illustrates the fully exposed cured test specimens with cracks so intense they could not undergo simple compressive strength tests.

For the mixtures with additives, the test specimens showed no curing problems, which were tested normally, measuring the water absorption and compressive strength without previous immersion and after immersion for 24 h before failure. Tables 4 to 6 show the mean strength of the test specimens cured under the three exposure conditions and tested after 28, 60 and 90 days of exposure, as well as the standard deviation, which considered failure under the same curing conditions and age, with and without immersion for 24 h before failure.

Table 7 shows the absorption test results carried out for all conditions and curing times of the mixtures tested, with the mean absorption and standard deviation of the specimens.

Figure 8 - Soil test specimens after immersion.

Figure 9 - Soil test specimens cured under full exposure.

4. Discussions

As for the compressive strength values, the soil specimens without additives broke apart when subjected to wa-

Table 4 - Mean compressive strength (μ) and standard deviation (σ), after curing in kiln oven.

Curing strength in kiln oven (without 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Mean compressive strength (kN/m^2)	1033.03	33.43	1852.48	46.29	1541.61	75.51
S-8-5		1048.33	33.93	2135.89	53.37	2665.45	119.64
S-8-10		1212.10	39.23	2168.25	54.18	2887.08	87.28
Curing strength in kiln oven (with 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Mean compressive strength (kN/m^2)	563.88	118.66	935.55	80.41	873.77	87.28
S-8-5		549.17	89.24	1393.52	45.11	1564.16	78.45
S-8-10		775.71	31.38	1486.69	69.63	2041.74	56.88

Table 5 - Mean compressive strength and standard deviation (σ), after full exposure.

Fully exposed curing strength (without 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Mean compressive strength (kN/m^2)	994.39	87.28	1524.93	96.11	1443.54	50.99
S-8-5		1341.55	127.49	1774.02	75.51	2185.90	70.61
S-8-10		1515.03	89.93	2333.00	47.07	2793.91	109.83
Fully exposed curing strength (with 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Mean compressive strength (kN/m^2)	383.44	75.51	887.50	188.29	742.36	43.15
S-8-5		394.23	614.99	1323.90	191.23	1608.29	81.40
S-8-10		672.74	183.38	1296.44	205.94	1609.27	94.14

Table 6 - Mean compressive strength and standard deviation (σ), after water immersion cure.

Curing strength with water immersion (without 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Mean compressive strength (kN/m^2)	1187.59	80.41	1943.68	20.59	2011.34	102.97
S-8-5		1574.95	79.43	2570.32	63.74	3103.80	90.22
S-8-10		1788.73	64.72	2814.51	107.54	3433.31	52.96
Curing strength with water immersion (with 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Mean compressive strength (kN/m^2)	726.67	96.11	954.19	86.30	1071.87	107.87
S-8-5		526.62	100.03	1426.87	49.03	1834.82	129.45
S-8-10		709.02	77.47	1840.71	120.62	2526.19	146.12

ter immersion and showed strong cracking when cured in the sun, to the point of ruling out the strength compression test. Therefore, the experimental protocols that had been proposed were not applied. However, this behavior was not observed for the specimens molded with the soil-lime and soil-lime-ash mixtures, probably because of the pozzolanic effect due to the presence of lime in the mixture. This is in agreement with Abiko (1984), which distinguishes the behavior of the soil with chemical additives for the soil without additives. The compressive strength test results show more clearly the effect of the presence of ash on the mixture, particularly for older ages, such as 60 and 90 days. The results in Tables 4 to 6 show the mechanical strength increase of the mixtures during the curing period for all the types of cure analyzed, except for the data obtained for the kiln curing conditions and the fully exposed cure conditions of the soil-lime mixture, for curing times of 60 and 90 days, which showed a slight strength decrease.

Figures 10, 11 and 12 illustrate the results presented in Tables 4 to 6, for all types of mixtures and curing conditions. The soil-lime mixture (8%) was considered as a reference composition. Thus, Table 8 presents the percentage relationship between the strength reached by the soil-lime samples (8%), rice-husk ashes (5%) and soil-lime (8%), rice-husk ash (10%) compared to the strength reached by the soil-lime mixture (8%).

For the lime-soil mixture, in all types of curing, the occurrence of a maximum strength peak was observed at 60 days of curing, which stands out for soil-lime-ash mixtures, where a continuous mechanical strength increase is observed with time and with the ash content incorporated. The results indicate, as an advantage, that the maximum point is for the older ages for the percentages of ash in the mix. The growth rates are, for practical purposes, the same for 8 and 10% of ash incorporated.

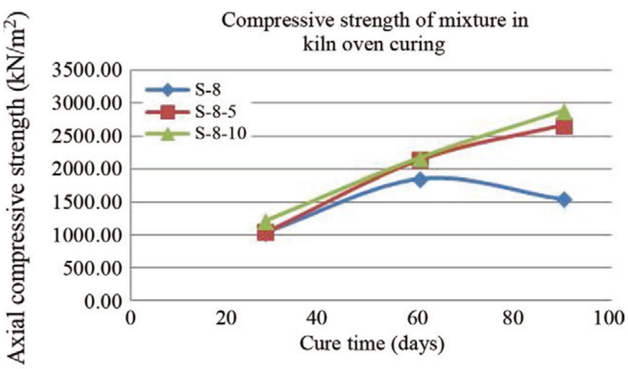

Figure 10 - Compressive strength of mixtures in kiln oven curing (kN/m^2).

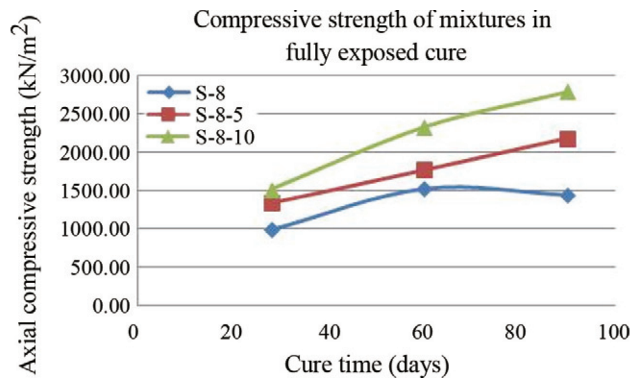

Figure 11 - Compressive strength of mixtures in fully exposed cure (kN/m^2).

The compressive strength values were approximately 50 to 70% lower than those shown in Alcântara *et al.* (2010), at 28, 60 and 90 days of cure, independent of the type of curing, considering that in the work of these authors, failure was for the specimens cured in a moist chamber with no water immersion. However, it was hoped that the results obtained in both works were not so dissimilar, and this fact could be related to the reactivity of lime, since even for the soil-lime mixture (8%), the decrease was also in the same order. However, comparing Figs. 10 to 12, it was observed that the types of mechanical strength curves generated were similar to those shown in Alcântara *et al.* (2010).

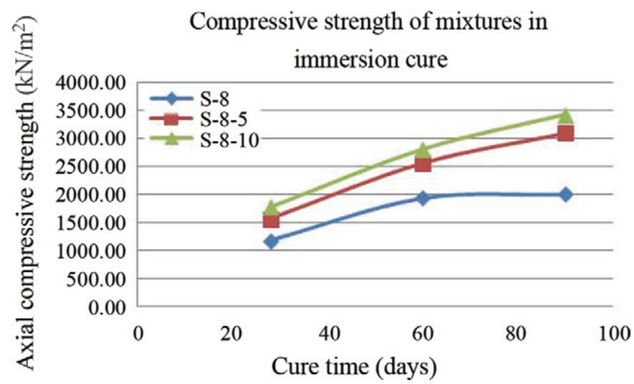

Figure 12 - Compressive strength of mixtures in immersion cure (kN/m^2).

Table 7 - Mean absorption and standard deviation of the specimens.

Curing absorption in a kiln oven (%)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Values (%)	20.33	0.44	15.01	0.53	15.21	0.38
S-8-5		22.09	0.35	18.13	0.28	16.82	0.22
S-8-10		21.03	0.4	18.44	0.35	17.22	0.5
Cure strength (with 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Values (%)	20.9	0.32	15.44	0.52	14.72	0.78
S-8-5		20.64	0.6	17.43	0.55	15.68	0.32
S-8-10		23.43	0.33	18.89	0.31	16.82	0.43
Cure strength (with 24 h immersion)							
Mixture	Cure time (days)	28		60		90	
		μ	σ	μ	σ	μ	σ
S-8	Values (%)	20.74	0.56	16.01	0.8	15.59	0.55
S-8-5		22.05	0.34	17.97	0.2	16.75	0.46
S-8-10		21.57	0.54	18.51	0.63	17.93	0.51

Table 8 - Relative strength between soil-lime-ash (levels of 5% and 10% of ash) and soil-lime mixtures.

Relative strength for kiln oven curing				
Mixture	Cure time (days)	28	60	90
S-8-5	Values (%)	102.99	115.30	172.90
S-8-10		119.08	118.63	187.28
Relative strength for fully exposed curing				
Mixture	Cure time (days)	28	60	90
S-8-5	Values (%)	134.91	116.33	151.43
S-8-10		152.85	152.99	193.55
Relative strength for immersed curing				
Mixture	Cure time (days)	28	60	90
S-8-5	Values (%)	132.62	132.24	154.31
S-8-10		150.62	145.26	170.70

For a better visualization of the relationship between the type of cure and the mechanical strength variation, Figs. 13 to 15 show the mechanical strength variations in the mixtures used; soil-lime (8%), soil-lime (8%), ash (5%) and soil-lime (8%) ash (10%).

Figures 13 to 15 show more clearly the relationship between the type of exposure and mechanical strength of the specimens of the soil-lime-ash mixtures over time, confirming that the best curing condition was the one under water immersion, followed by curing in a kiln oven, and lastly the cure fully exposed to the elements. Table 9 shows the approximate angular coefficients for the curves that express the development of mechanical strength for the parts relating to the curing periods of 28 to 60 days and 60 to 90 days. These express the change rates for the strength values.

It can then be observed that for ages 28 to 60 days, there are higher values for the immersed and kiln oven cures, and lower values for fully exposed cures. For 60 to 90 days of cure, the values generally tend to be lower than for those of 28 to 60 days, and higher for immersed cure and for cases where the ash content is higher. As for the mixtures without ash, negative values can be seen in the angular coefficients, due to the decrease in strength with the curing time, and in the case of fully exposed cure and with ashes, there is an upwards displacement of the curve, increasing the ash content, indicating that there may be an improved

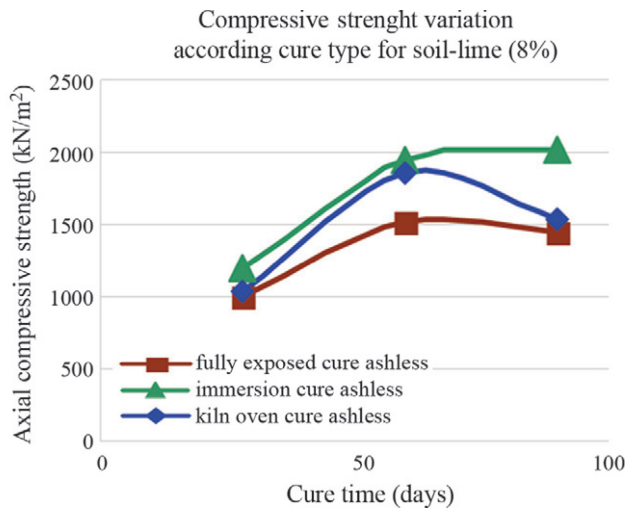

Figure 13 - Compressive Strength Variation according cure type for soil-lime (8%), (kN/m^2).

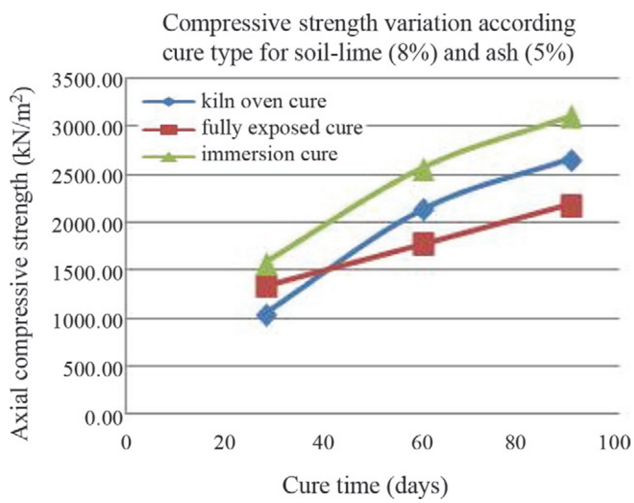

Figure 14 - Compressive Strength Variation according cure type for soil-lime (8%) and ash (5%), (kN/m^2).

Table 9 - Approximate angular coefficients for the curves regarding mechanical strength gains in the various curing times and exposure conditions.

	Types of exposure conditions					
	Immersed cure		Kiln oven cure		Fully exposed cure	
	Curing periods (days)					
Mixtures	28-60	60-90	28-60	60-90	28-60	60-90
S-8	0.24	0.002	0.27	-0.11	0.17	-0.03
S-8-5	0.32	0.18	0.35	0.18	0.14	0.14
S-8-10	0.33	0.18	0.31	0.23	0.26	0.16

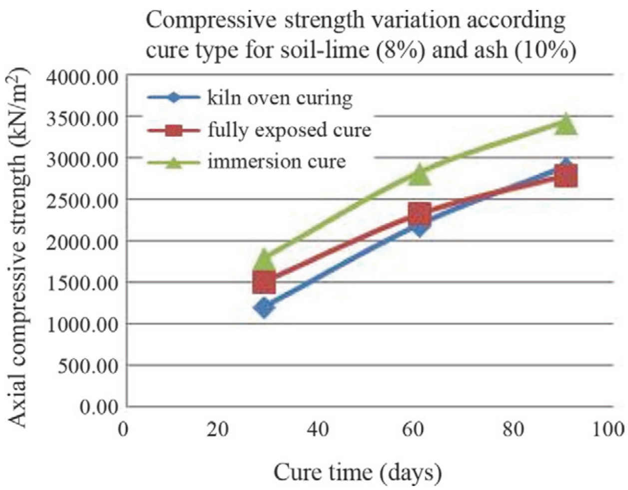

Figure 15 - Compressive Strength Variation according cure type for soil-lime (8%) and ash (10%), (kN/m^2).

performance of the material due to the exposure conditions with the incorporation of ash.

Table 10 shows the differences in strength values, given in absolute values and percentages, when considering the types of immersion and kiln oven cures, and by immersion and fully exposed cures. For the first case, the absolute differences of values were enhanced by the presence of ash. Although the absolute differences show little change when the different curing ages are considered, in which case the percent values were always lower over time for the mixtures with ash since the base values increased, as seen in the data in Table 10 and Fig. 16. As for the mixture without ash, there is a return to the percentage increase at 90 days, due to the decreasing strength value of the ash mixture in a kiln oven. According to the data in Table 10 and Fig. 17, when comparing the immersed and fully exposed cures, the absolute differences and percentages increased, since the increase of the strength rates was higher for the immersed cures. Apparently the presence of ash may have greater efficacy in the immersed cure, and for the exposed cures, they are benefitted by the increasing ash content.

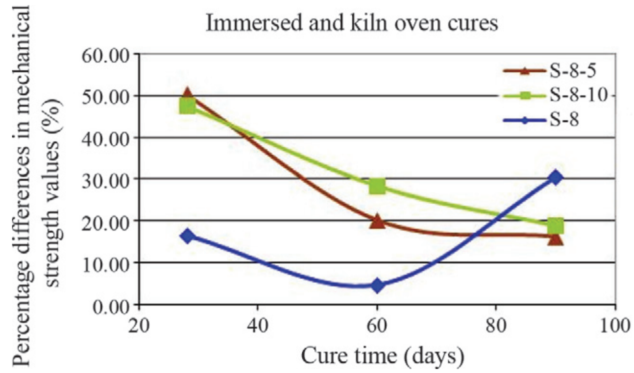

Figure 16 - Percentage differences of the mechanical strength values when compared to the immersed and kiln oven cures.

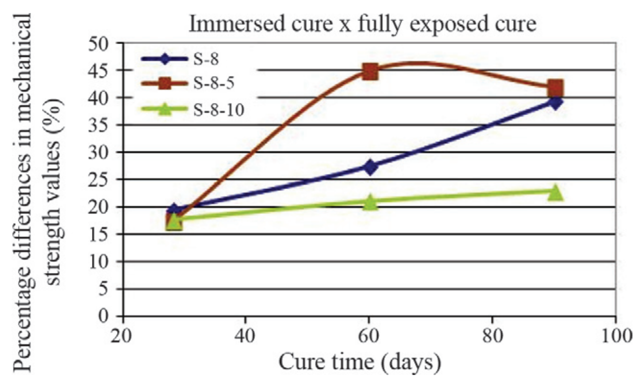

Figure 17 - Percentage differences of the mechanical strength values when compared to the immersed and fully exposed cures.

It is believed that the best curing performance is under immersion, when compared to the other modalities. This could be due to the fact that in this condition the specimens are protected from the effects of expansion and thermal contraction cycles and of absorption and drying, which may induce the microcracking of the material. The cure exposed to the contraction and shrinkage effects on the specimens of the mixtures were significantly higher, due to diurnal temperature variations and wetting and drying cycles promoted by

Table 10 - Values of the absolute and percentage differences for the mechanical strength increase compared to the immersed curing condition and kiln oven curing and fully exposed curing.

		Days of curing					
		28		60		90	
		Absolute	%	Absolute	%	Absolute	%
Immersed and kiln oven cures	S-8	1.73	16.7	0.93	4.9	4.79	30.47
	S-8-5	5.37	50.23	4.43	20.34	4.47	16.45
	S-8-10	5.88	47.57	6.38	28.47	5.57	18.92
Immersed cure and fully exposed cure	S-8	1.97	19.43	4.27	27.43	5.79	39.33
	S-8-5	2.38	17.40	8.12	44.89	9.36	41.00
	S-8-10	2.74	17.69	5.0	21.02	6.32	22.89

rain, followed by sunny days, which can negatively influence the development of mechanical strength. The immersed cure, as can be seen, is the only one that showed no increased negative resistance at 90 days of cure, for mixtures without ash. Another aspect is that this apparently favors the pozzolanic activity exerted by lime and ash and the active components in the soil, possibly due to the existence of an ever-present soil solution in the pores, which helps to facilitate ionic migration and the interaction of lime with the soil, with the formation of cementitious composites.

The saturation influence prior to compression strength can be seen with the data presented in Table 11, which shows the percentage relationship between the mechanical strength of the specimens of the mixtures obtained after saturation for 24 h prior to failure and those determined without saturation. The data in Table 11 shows that the saturation systematically reduced the mechanical strength of the specimens of the mixtures. Considering the cure times or the addition of ash, as well as the content incorporated, some changes can be observed in the values or in the stabilization tendencies. However there is an indication that the relative strength increases with the cure time and with the ash content incorporated. For the immersed and kiln oven cures, the values increase with cure time and with ash content at 60 days, as for the cure fully exposed to the elements, there are oscillations for the cure period and ash content. For the cure period of 28 days, the results oscillate for all types of cure.

As for the absorption values, the results in Table 12 indicate that these generally increase, particularly when ash was incorporated, and also increased with their content. This is in agreement with the hygroscopic nature that can be attributed to the ashes. However, the decrease or stabilization tendency with curing time can be observed, according to Figs. 18, 19 and 20, which illustrate the results shown in Table 7 for kiln oven, fully exposed and immersion cures, respectively. For 60 and 90 days of cure, it was seen that

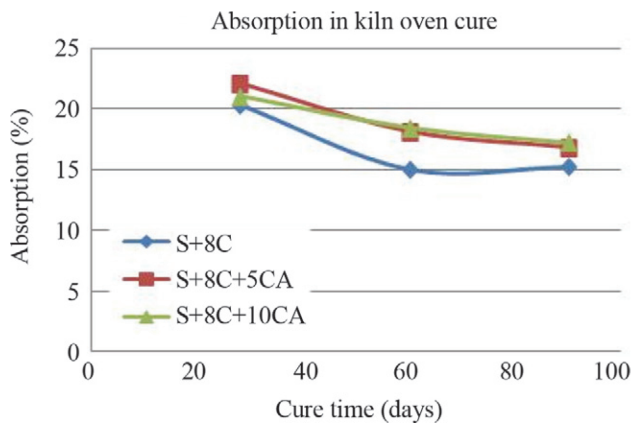

Figure 18 - Absorption in kiln oven cure (%).

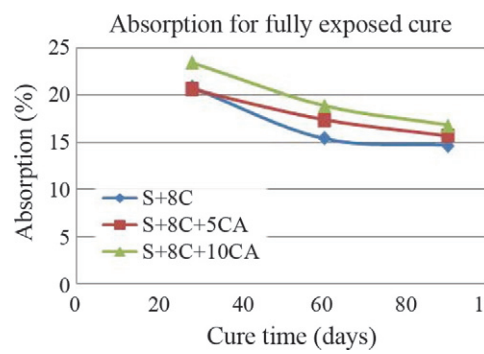

Figure 19 - Absorption for fully exposed cure (%).

Table 11 - Relative strength between rupture prior to immersion of 24 h and without immersion of 24 h.

Relative strength between rupture prior to immersion of 24 h and without immersion of 24 h. Moist-chamber cure				
Mixture	Cure time (days)	28	60	90
S-8	% of strength achieved at mean value	55.39	50.50	56.68
S-8-5		52.39	65.24	58.28
S-8-10		64.00	67.65	70.72
Relative strength between rupture prior to immersion of 24 h and fully exposed cure.				
Mixture	Cure time (days)	28	60	90
S-8	% of strength achieved at mean value	38.56	58.20	51.43
S-8-5		30.70	74.63	73.58
S-8-10		44.26	55.57	57.60
Relative strength between rupture prior to immersion of 24 h and without immersion of 24 h.				
Mixture	Cure time (days)	28	60	90
S-8	% of strength achieved at mean value	61.19	49.09	53.29
S-8-5		33.44	55.51	59.12
S-8-10		39.64	65.20	73.58

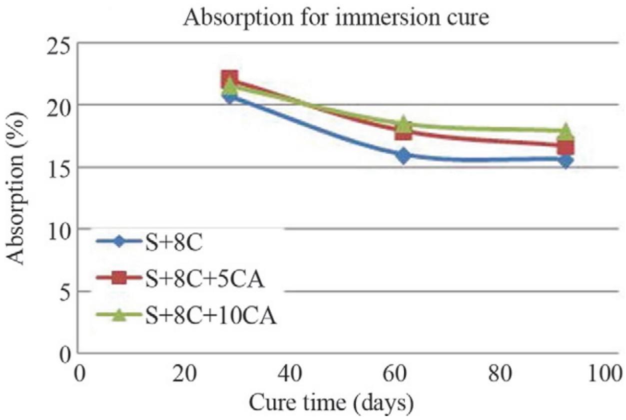

Figure 20 - Absorption for immersion cure (%).

Table 12 - Mean absorption values, in percentage, for mean relative strength values for all types and cure ages.

Kiln oven cure			
Days of cure	28	60	90
Absorption (%)	21.15	17.19	16.42
Relative strength (%)	57.26	61.13	62.03
Fully exposed cure			
Absorption (%)	21.36	17.25	15.74
Relative strength (%)	37.84	62.8	60.19
Immersed cure			
Absorption (%)	21.45	17.5	16.76
Relative strength (%)	44.76	56.6	62.00

while the mixes without the addition of ash appear to be stabilized with respect to absorption values, the ash mixes show they are still subject to more significant reduced values. The absorption behavior with time is different than that shown in Alcântara *et al.* (2011), because in that case the values increase over curing time and in this case the final values shown are lower, however the degree of compression was lower, about 95%, than the normal Proctor.

In order to associate the absorption values in the presence of voids due to microcracking, a correlation between the absorption values was set with the relative strength values, in percentage. The data in Table 12 shows that there is a tendency that the mean values of the relative resistance will grow inversely proportional to the mean absorption values. This appears to be consistent with the possibility for internal microcracking of the specimens and voids. On the other hand, according to the data in Table 13, it can be seen that even with the absorption increase due to the addition of ash, the relative strength values can increase, possibly due to the cementing achieved.

Figure 21 shows the variation of the mean relative strength value with the mean absorption value, decreasing, compared to the absorption values, independent of the cure time.

It was expected that there would be a significant difference between the absorption of the specimens cured in a

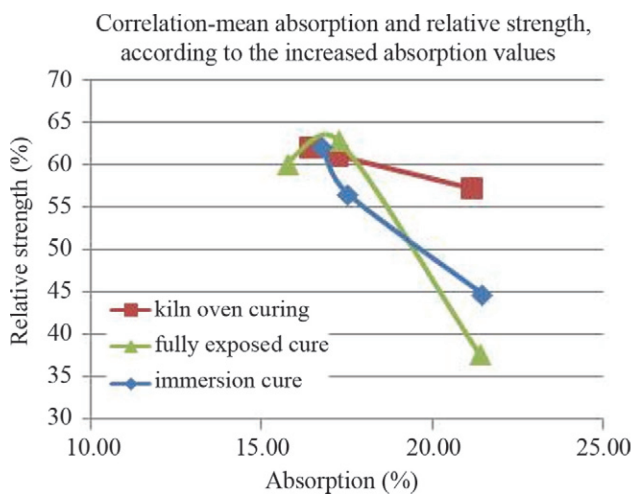

Figure 21 - Correlations between the mean absorption values and the relative strength, according to the increased absorption values.

Table 13 - Mean absorption values, in percentage, for mean relative strength values for the compositions, types and cure age.

Kiln oven cure									
Days	28			60			90		
Mixtures	S-8	S-8-5	S-8-10	S-8	S-8-5	S-8-10	S-8	S-8-5	S-8-10
Absorption (%)	20.33	22.09	21.03	15.01	18.13	18.44	15.21	16.82	17.22
Relative strength (%)	55.39	52.39	64.00	50.5	65.24	67.65	56.68	58.68	70.72
Fully exposed cure									
Absorption (%)	20	20.64	23.43	15.44	17.43	18.89	14.72	15.68	16.82
Relative strength (%)	38.56	30.7	44.26	58.2	74.63	55.57	51.43	73.58	57.6
Immersed cure									
Absorption (%)	20.74	22.05	21.57	16.01	17.97	18.51	15.59	16.76	17.93
Relative strength (%)	61.19	33.44	39.64	49.09	55.51	65.2	53.29	59.12	73.58

kiln oven and under immersion, compared to the fully exposed cured ones, due to the higher cracking produced in the latter case. However, what was seen in this case was a lower absorption. However, it showed a higher sensitivity to saturation with decreasing relative strength, as illustrated in Fig. 21, with the best cure performance, in this regard, achieved in a kiln oven.

5. Conclusions

Based on the results already presented and discussed in this work, in general it can be seen that the results show the advantages of using ash as an auxiliary additive in soil-lime mixtures, increasing value with the ash content, particularly promoting mechanical strength increase and maintaining this value in the long-term, including the reduced influence of the saturation conditions on the compressive strength. Curing by immersion was the one that best promoted mechanical strength increase. The water absorption values increased with the incorporation of increasing amounts of ash and curing time. Specifically conclusions are, as follows:

- The addition of rice husk ash produced a compressive strength increase, up to the 90-day curing period analyzed, in all cure forms studied;
- The immersion cure of the specimens of the mixes was the best out of those tested, improving their performance with the addition of ashes;
- Adding the ash to the soil-lime mixture influenced the water absorption, with a direct relationship between increasing the value of this parameter and increasing the ash content and the curing time of the mixtures, for all the cure conditions tested;
- Adding 10% of ash into the mixture was more effective to increase the mechanical strength than for the cases without addition and with the addition of 5% ash, for all the cure types analyzed; and
- The addition of ash contributed to improving the mechanical strength against saturation conditions, thereby minimizing performance loss, by increasing the ash content applied and with the increasing cure time and the ensuing development of cementation reactions.

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