Evolution of the Mechanical Properties of a Tropical Soil Stabilized with Lime and Ash of Rice Rind

Marco Antônio de Morais Alcantara, Lucas Pereira dos Santos, Dario Cardoso de Lima

Abstract. The ash of rice rind is a pozzolanic material that reacts with the calcium hydroxide (Ca $(OH)_2$) forming bonding composites, when finely worn out and in water presence. Considering this behavior, the objective of the present work was to evaluate the potential use of this residue in the enrichment of the content of pozzolanic materials of a tropical soil stabilized with a commercial hydrated lime. The laboratory testing program incorporated unconfined compression strength tests performed on the soil and on its mixtures with contents of 8% of lime enriched with 5 and 10% of ash of rice rind in relation to the soil dry mass. The results of the testing program supported that the use of the residue was effective in increasing the degree of reactivity of the soil that was also directly related with the increase in the ash content and the period of cure of the mixtures.

Keywords: soil improvement, soil-lime-ash of rice rind mixture, enrichment of pozzolanic activity, mixture unconfined compressive strength.

1. Introduction

The Brazilian road engineering experience with soil-lime mixtures dates back to the decade of 1960, initially at the research level that was reported by: (i) Pinto (1964), referring to the stabilization of a A-7-5 soil using little amounts of hydrated lime and measuring mixtures mechanical strength via unconfined compression and CBR tests; (ii) Pinto (1965), analyzing the data from a Brazilian study including an universe of eight soils and seven hydrated commercial limes; (iii) Baptista (1969), informing the results of a study including data on the grain size distribution, Atterberg limits and mechanical resistance of soils from the state of Rio de Janeiro, Brazil.

Regarding soil-lime mixtures, the Brazilian National Department of Transportation Infrastructure-DNIT (DNIT, 2006) defines soil-lime stabilization as those composites using lime contents in the range of 5 to 6% that develop expressive tensile strength for application as bases and subbases of road pavements, as well as modified soil-lime mixtures in those applications using lime contents of 1 to 3% that do not show high tensile strengths and can be classified as flexible pavement layers.

The soil-lime stabilization is characterized as a procedure that modifies the clayey soil particles surface chemical conditions in order to promote changes in soil CTC and formation of new cementing composites as reported by TRB (1976) and Alcântara (1995) that are, respectively, responsible for short and medium/long term changes in soil mechanical engineering behavior. According to Lima (1981), Pinto (1985) and Alcântara (1995) short term modifications in soil lime mixtures are those that happen just after addition of lime, commonly referred to an increase in the plasticity limit, and decreases in the liquidity limit and in the plasticity index, as well as flattening of the compaction curves with increase in the optimum moisture content and decrease in the dry density. On the other hand, medium and long term modifications are due to pozzolanic reactions with formation of calcium and aluminate silicates that improve soil mechanical strength and durability.

The pozzolanic reactions are understood as those that happen between the inorganic components of a soil and the Calcium hydroxide $Ca(OH)_2$, forming insoluble composites, even under immersion conditions, similarly to the obtained in the Portland cement hydration (Cincotto & Kaupatez, 1984). Alcântara (1995) emphasizes that a soil has a pozzolanic activity degree that is directly related to its clay fraction type and content.

Considering that soil-lime mixtures are soil composition dependent, each mixture demands an specific laboratory design, generally, based on unconfined compressive strength (general procedure), CBR (modified soil-lime mixtures) and dry/wetting durability specimen testing. In this sense, Alcântara (1995) analyzed the soil-lime stabilization of three soils from the city of Ilha Solteira, São Paulo State, Brazil, classified as A-2-4, A-4 and A-7-6 using lime contents ranging from 2 to 10% and mixtures curing times of 3, 7, 28, 90, 120 and 180 days. Another parameter that affects soil-lime mixtures mechanical response is the mixture dry density. Segantini and Alcântara (2007) understand that the soil-lime unconfined compressive strength resistance fundamentally depends on specimen laboratory molding conditions, water content and compaction effort.

Marco Antônio de Morais Alcantara, PhD., Assistant Professor, Departamento de Engenharia Civil, Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista "Júlio de Mesquita Filho", 15385-000 Ilha Solteira, SP, Brazil. e-mail: alcantar@dec.feis.unesp.br.
Lucas Pereira dos Santos, Civil Engineer, Stahldach Construções/Grupo Marko, 02518000 São Paulo, SP, Brazil. e-mail: lsantos@marko.com.br.
Dario Cardoso de Lima, PhD., Professor, Departamento de Engenharia Civil, Universidade Federal de Viçosa, 36570-000 Viçosa, MG, Brazil. e-mail: declima@ufv.br.
Submitted on May 19, 2009; Final Acceptance on December 8, 2009; Discussion open until December 31, 2010.

The ash of rice rind is a natural residue from rice industry classified as a pozzolanic material, according to Cincotto and Kaupatez (1984). When finely grounded and in presence of water, this material reacts with lime calcium hydroxide ($Ca(OH)_2$) forming cementitious compounds. In Brazil, the agro-industrial improvement and commercialization of rice stands out for the high production of this residue, representing an environmental problem. When it is not used in a direct way, as in the case of the hen house bed or as soil conditioning, the rice rind is discarded and thrown in embankments and local highways, burned to open sky or used as fuel for grain drying, producing tons of ashes that are considered harmful to the human health as emphasized by Milani (2005). Data from the Brazilian Institute of Geography and Statistics (IBGE, 2007) show that Brazil produced around 2.3 million tons of ash rice rind in 2006.

According to Barbosa (2007), when ash of rice rind is roasted, 20% of it is turned into ashes reaching the available silica amount of 95%. Still according to this author, types of ash rice rind can be amorphous or crystalline, depending on the used burning process. Ashes produced at lower controlled temperature (450-500 °C) tend to be amorphous, while those produced at higher not controlled temperature tend to be crystalline; the first ones are considered to be the most reactive in soil stabilization processes.

This research was directed to the use of the ash of rice rind for the improvement of the clayey fraction of a tropical residual soil of gneiss stabilized with hydrated lime for road engineering applications taking advantage of its physical-chemical potentiality as a pozzolanic material and minimizing environmental drawbacks.

2. Materials and Methods

This research was developed at the Laboratory of Civil Engineering of the Faculty of Engineering of Ilha Solteira, UNESP, and at the Laboratory of Civil Engineering of the Energy Company of the State of São Paulo (CESP), Brazil.

2.1. Materials

A silt-clay-sand soil classified as A-4 (DNIT, 2006) and as red-yellow argissol (EMBRAPA, 2006) from the city of Ilha Solteira, State of São Paulo, Brazil, a commercial CH-III hydrated lime (ABNT, 2003), and a crystalline ash of rice rind from the city of Pelotas, State of Rio Grande do Sul, were used throughout the study.

The ash of rice rind was sampled after 30 min of grinding process in a mill of balls of the CESP's Laboratory of Civil Engineering located in Ilha Solteira, and specifically designed for the production of cement. Table 1 presents the physical and chemical characterizations of the sample of this residue.

2.2. Methods

After sampling, the soil sample was passed through the #4 sieve, and dried in air in order to determine its hygro-

Table 1 - Physical and chemical characterizations of the crystalline ash of rice rind.

Sample		Ash of rice rind	Requirements for pozzolanic materials (ABNT, 1992)	
			Minimum value	Maximum value
Apparent density (g/cm^3)		0.60	-	-
Absolute density (g/cm^3)		2.14	-	-
Grain size (micra)		20.13	-	-
Water content (%)		1.08	-	3.0
Chemical analysis data (%)	Fire loss	7.95	-	6.0
	SiO_2	85.37	-	-
	Fe_2O_3	0.86	-	-
	Al_2O_3	1.19	-	-
	CaO	1.34	-	-
	MgO	0.33	-	-
	SO_3	0.06	-	5.0
	$Al_2O_3 + Fe_2O_3$	2.05	-	-
	$SiO_2 + Al_2O_3 + Fe_2O_3$	87.42	70.0	-
	Na_2O equivalent alkaline (available)	0.42	-	-
	Na_2O	0.03	-	-
	K_2O	0.60		-

Table 2 - Soil, lime and ash rice rind mixture compositions used in the study.

Mixture	Soil, lime and ash of rice rind percentile composition
1	Soil + 8% lime + 0% ash of rice rind
2	Soil + 8% lime + 5% ash of rice rind
3	Soil + 8% lime + 10% ash of rice rind

scopic water content, and Table 2 presents the mixtures percentile combinations referred to soil dry mass used in the study.

Specimen preparation was carried through weighing the soil, lime and ash of rice rind, mixture of these materials in a plastic bag, addition of water in order to reach the optimum moisture content, mixture sieve through the #10 Brazilian Association of Technical Standards (ABNT) sieve mesh, and compaction at the Standard Proctor compaction energy using the mini-CBR molding apparatus (Nogami e Villibor, 1995) following the Brazilian NBR 12024 Standard (ABNT, 1990a). After molding triplicate 5 cm diameter to 5 cm height specimens, they were weighed and measured in order to determine their compaction degree, and kept curing for 7, 28, 60 and 90 days in a standard humidity chamber. After curing, the specimens were tested in laboratory under unconfined compression conditions using a 50 kN load frame apparatus according to the Brazilian NBR 12025 (ABNT, 1990b). The average value of the unconfined compressive strength of three tested specimens was adopted.

3. Results

3.1 Compaction testing data

Table 3 and Fig. 1 introduce, respectively, the soil and mixtures compaction curves and optimum compaction test parameters.

Table 4 shows the values of the degree of compaction of mixtures specimens compacted in the mini-CBR molding apparatus, where it can be noted that the values of degree of compaction ranges from 98 to 99.5%.

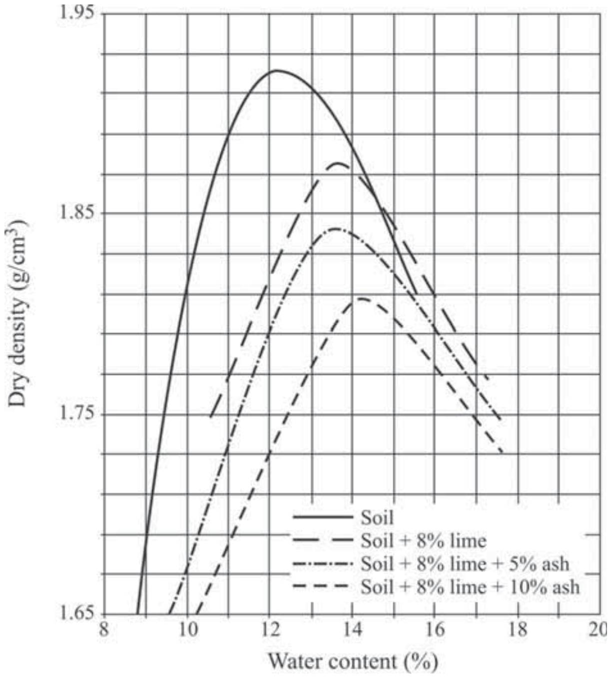

Figure 1 - Compaction curves of soil and its mixtures with lime and ash of rice rind.

Table 3 - Optimum compaction testing parameters of soil and mixtures: optimum moisture content (w_{ot}); maximum dry density (γ_{dmax}).

Soil and mixture compositions	w_{ot} (%)	γ_{dmax} (g/cm^3)
Soil	12.4	1.92
Soil + 8% lime	13.7	1.88
Soil + 8% lime + 5% ash of rice rind	13.7	1.84
Soil + 8% lime + 10% ash of rice rind	14.4	1.81

3.2 Unconfined compression testing data

Table 5 presents the mean values of the unconfined compressive strength, and Fig. 2 depicts the respective percentile variations of mixtures parameters.

Table 4 - Mean values (μ) and standard deviation (σ) of degree of compaction of mixtures specimens after periods of cure of 7, 28, 60 and 90 days.

Mixture content	Degree of compaction (%)							
	Period of cure (day)							
	7		28		60		90	
	μ	σ	μ	σ	μ	σ	μ	σ
Soil + 8% lime	99.0	2.31	98.5	0.40	98.5	0.5	98.5	0
Soil + 8% lime + 5% ash of rice rind	99.5	0	98.0	0.45	98.5	0.5	98.0	0

Table 5 - Mean values (μ) and standard deviation (σ) of the unconfined compressive strength of mixtures specimens after periods of cure of 7, 28, 60 and 90 days.

Mixture content	Unconfined compressive strength mean values (MPa)							
	Period of cure (day)							
	7		28		60		90	
	μ	σ	μ	σ	μ	σ	μ	σ
Soil + 8% lime	0.69	0.06	4.60	0.11	6.79	0.36	6.70	0.37
Soil + 8% lime + 5% ash of rice rind	0.64	0.015	4.13	0.55	6.54	0.29	7.81	0.73
Soil + 8% lime + 10% ash of rice rind	0.57	0.02	4.70	0.15	8.65	0.63	10.54	1.77

4. Discussions

Data from Fig. 1 and Table 3 support that addition of lime and ash of rice rind caused drops in the soil maximum dry density and increases in the soil optimum moisture content of the mixtures.

Table 5 presents the average values of unconfined compressive strength of soil-lime-ash of rice rind mixtures. For the first ages of cure, values of mechanical strength of the tested mixtures tend to be lesser than those of the reference mixture, mainly regarding the 7 days cure. On the other hand, for advanced periods of cure (60 and 90 days), the values of mechanical strength tend to surpass those presented by the reference mixture, especially for the period of cure of 90 days. Comparing the behaviors of the 10% ash and the reference mixtures, it is observed gains around 2, 27 and 57%, respectively, for the periods of cure of 28, 60 and 90 days.

Figure 2 shows that the addition of 10% of ash was highly efficient in promoting the increase of the unconfined compressive strength of the reference mixture, since after 28 days of cure the values of the percentile variation are positive. By contrast, the mixture with 5% of ash was less reactive, presenting negative percentile variation up to 60 days of cure; however, presenting a decreased trend in the difference, becoming positive for higher period of cure, that certifies the influence of the period of cure in the development of pozzolanic reactions in the ash mixture. Comparing the mechanical response of the 5 and the 10% ash content mixtures, it is observed that the later presented larger gains of mechanical strength at medium and long term periods of cure, indicating the significant influence of the addition of a higher content of ash in the development of pozzolanic reactions.

Figure 3 introduces the evolution of the mechanical strength of the tested mixtures with the period of cure. In this figure, the parameter unconfined compressive strength of the soil-lime mixture presents a stable behavior starting at 60 days of cure. On the other hand, at this period, the value of the mechanical strength of the mixture with 5% of ash already approaches the value presented by the reference composition, coming to overcome it at 90 days of cure as previously reported. Regarding the mixture with 10% of ash, it already reached the standard mixture mechanical strength at 28 days of cure being consistently higher than that of the 5% mixture of ash which emphasizes the influ-

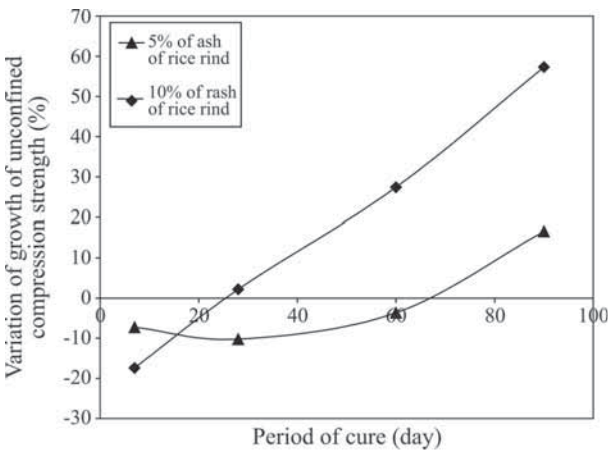

Figure 2 - Percentile variation of the increase of unconfined compressive strength versus periods of cure (7, 28, 60 and 90 days) adopting as reference the unconfined compressive strength of the soil-lime mixture.

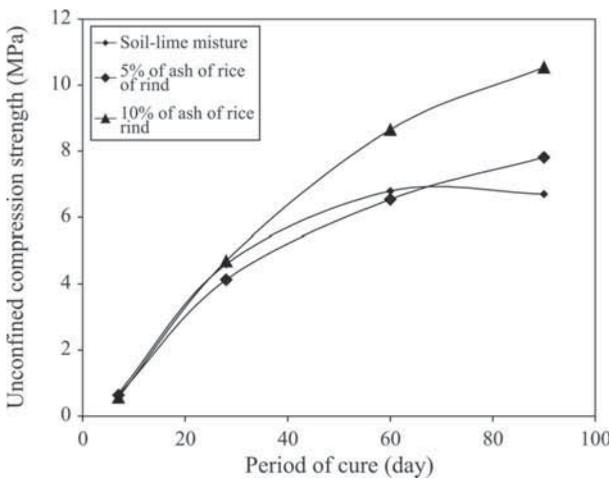

Figure 3 - Evolution of the mechanical strength of mixtures with the period of cure.

Table 6 - Dry density of mixture specimens tested after the periods of cure of 7, 28, 60 and 90 days.

Mixture	Dry density (g/cm^3)			
	Period of cure (day)			
	7	28	60	90
Soil + 8% lime	1.86	1.85	1.85	1.85
Soil + 8% lime + 5% ash	1.83	1.80	1.81	1.80
Soil + 8% lime + 10% ash	1.80	1.77	1.77	1.79

ence of the time and ash content on the evolution of the standard mixture mechanical response. This behavior can be also visualized through data presented in Fig. 4 which depicts the variation of the unconfined compressive strength with the ash contents of the standard mixture.

Table 6 illustrates the influence of addition of ash in the values of the dry density of the mixtures. Analyzing the data in this table and comparing with the standard mixture response, it is obvious that the drops in the values of dry density of the mixtures are related to the increase in the ash content, a lighter material than soil and lime. Certainly, the values of unconfined compressive strength presented in Table 5 reflect the possible influence of the variation of the dry density in the mechanical response of the mixtures, mainly reflecting the incipient development of pozzolanic reactions at 7 days period of cure (short term reactions). Larger periods of cure definitely increase the effect of the pozzolanic reactions in the gain of mechanical strength of the mixtures, also supplanting the deleterious effect of the observed dry density fall.

Finally, Fig. 5 shows an analysis of the relationship between dry density and unconfined compressive strength of all tested mixtures for different periods of cure. It is observed in this figure that there is no correlation between dry density and unconfined compressive strength of mixtures at the period of cure of 7 days. Increasing the period of cure, it is noticed the development of correlations between these

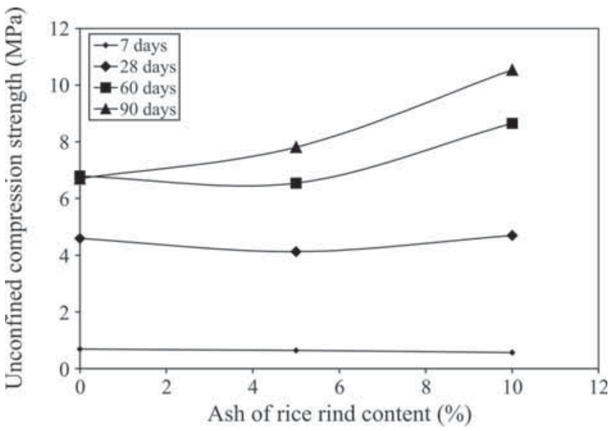

Figure 4 - Unconfined compressive strength versus ash of rice rind content and period of cure of mixtures.

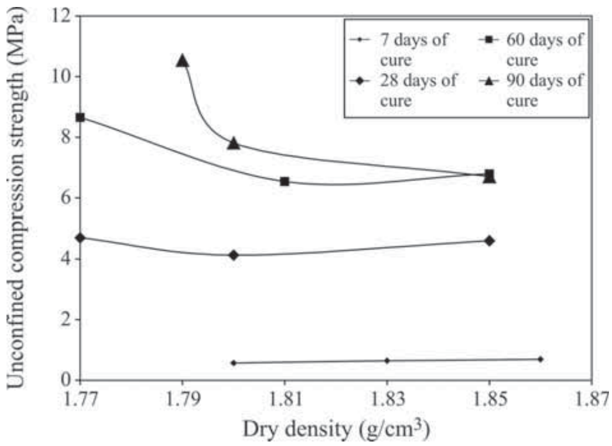

Figure 5 - Variations of dry density and unconfined compressive strength with periods of cure.

two parameters that reaches a maximum at 90 days, emphasizing the effect of the period of cure on the development of the pozzolanic reactions in the tested mixtures.

5. Conclusions

Based on the laboratory testing data, the conclusions are as follows:

• Addition of ash of rice rind increased the soil reactivity degree, and the increase in the pozzolanic effect was directly related to the ash content and the periods of cure of mixtures;

• The pozzolanic effect of the addition of the ash of rice rind to the soil-lime mixture compensated the effect of the decrease on the dry density of the mixtures for periods of cure of 60 and 90 days;

• The 10% ash content produced the largest increase on the mechanical strength of the soil-lime mixtures.

Acknowledgments

The research described in this technical note was supported by FAPESP. This support is gratefully acknowledged. The authors wish to thank the technicians of the Laboratory of Civil Engineering of the Energy Company of the State of São Paulo (CESP), and of the Laboratory of Materials of Construction of the UNESP-Ilha Solteira, for their support and collaboration in the execution of the tests.

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