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Experimental analysis of the addition of rice husk ash to the clayey subgrade of a road stabilized with lime

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Abstract. There are many studies about how the addition of lime and rice husk ash (RHA) gives the soil a better mechanical behavior, particularly on clayey soils, where usually fine particles reach more than 75%. However, the soils with a small presence of fine particles (59-60%) do not have much research. This analysis evaluates the influence that RHA has on this kind of soil stabilized with 3% of lime. After the initial mix of soil-lime, CBR increased 11.2 times its initial value; within the addition of the ash, the CBR averaged between 45-50% up until 28% of RHA was added, where the results decreased considerably. Soil workability improved and the specimens with more ash resulted in a more granular material, with a group index value 0 following the AASHTO standards. The greatest CBR record was obtained with the specimen of 16% RHA, 3% lime and soil, reaching a 51.3% CBR, 1.58g/cm3 of MDD and 16.5% of OMC. Yet, it only showed a 1.55% more resistance than the lime-soil specimen. The CBR with more presence of RHA tends to decrease its value, therefore for silica-rich clayey soils, the addition of lime by itself should be enough for an adequate performance.

1. Introduction

There are currently a variety of problems facing civil engineering in terms of road infrastructure: cuts, landfills, earthworks, land stabilization, etc. As far as stabilization is concerned, this often turns out to be expensive because of the materials used to achieve adequate resistance of the ground. If stabilization is avoided, there is a risk that settlements will occur due to the mobile loads acting on a road [1].

Peru is a developing country where there is no adequate road infrastructure in many of its provinces. Focusing on the jungle region, it has more than 60% of unpaved roads. In the northeast of the country, 80% of unpaved roads are registered for the transit of vehicles. Studies conducted by the National Institute of Civil Defense reported the presence of soils with a high percentage of fines, to more granular clayey soils, CL according to SUCS classification [2].

There are procedures to stabilize a soil for road construction. Techniques such as physical and chemical stabilizations with additions of cement, asphalt, and natural pozzolanas like pond ash, coconut shell ash, and polymers are known [1, 3, 4, 7, 8]. However, the additional information that has been gaining strength in recent times is the rice husk ash (RHA) which use is becoming popular for roads construction.

The production of 80 tons of rice, generates 20 tons of rice husk, which can be reduced by up to 15% after incineration producing RHA [3]. It is well known, that the RHA is rich in silica, bordering 90% of its composition, which is a higher concentration of SiO_2 than fly ash [4, 9, 10]. This characteristic of the ash shows its benefits when mixed up with CaO, for the pozzolanic reaction that occurs when both silica and calcium are combined. However, it is important to mention that these pozzolanic reactions show more effectiveness in long terms. In fact, the immediate reaction is the cation exchange between soil and lime which leads to flocculation, lime carbonatation and a molecular restructuration of the soil [3, 5, 6].

Previous research reminds us of the enhancement in the workability of the soil and its resistance, produced by this type of combination (lime-RHA), also accompanied by cement and fibers [5]. Rice husk ash is found in abundance in the northern region of the Peruvian jungle, which is characterized as the largest rice producer in the country [14]. The combination of lime and ash in clayey soils of the area needs to have more research due to the increasing generation of this industrial waste product which is leading to health issues at the zone. In addition to its easy obtaining and abundance, soil stabilization using RHA reports an improvement in durability especially in extreme conditions such as those present in the Peruvian jungle [14].

This article shows the effects of RHA on lime stabilization of a clayey road with 49.1% of sand.

2. Experimental investigation

2.1. Materials used

Soil was obtained from a clayey road located at Tarapoto-Peru, this place is mainly known for its rainy days and high temperatures along the year. Late researches lead by the local National University, designated that the land is predominantly CL, also obtaining SC, ML, MH according to USCS [2, 14]. Two samples where extracted from the place and the respective classification was made, according to de ASTM and AASHTO parameters, the soil in study was sample 2 which characteristics are shown in table 1.

Table 1. Physical characteristics of soil.

Basic characteristics	**Sample 1**	**Sample 2**
Color	Dark grey	Dark brown
Depth (m)	2.0m	2.5m
Natural water content (%)	7	5
Passing 80μm sieve (%)	47.3	50.9
Liquid limit (%)	39	40
Plastic limit (%)	17	16
Plasticity index (%)	22	24
USCS Classification	SC	CL
AASHTO Classification	A-6 (4)	A-6 (5)

Table 2. Combination of samples

ID	Sample mixture (%)		
	Soil	RHA	Cal
R0C0	100	0	0
R0C3	97	0	3
R11C3	86	11	3
R16C3	81	16	3
R22C3	75	22	3
R28C3	69	28	3

The ash was obtained from a local rice miller, which incinerates the husk in standardized ovens. Finally, the lime used for stabilization was hydrated lime at 65% [11]. This product, accepted by the country's regulations for soil stabilization, can be obtained in the local market. Mineralogical characterization of the materials was performed as shown in tables 3 and 4. LOI indicates the loss due to the ignition generated in the X-ray fluorescence assay.

2.2. Stabilized soil combinations

For the analysis, the percentages of rice husk ash were 0, 11, 16, 22 and 28%. Lime percentage had a fixed value of 3% throughout the study, supported as an amount accepted by local road regulations [12, 13]. The details of the mixtures used are shown in table 2. A total of 6 samples were studied with the compaction and CBR test.

Table 3. Chemical properties of soil and RHA

Item	Formula	Sample 2 (%)	RHA (%)
1	SiO2	68.41	92.5
2	Al2O3	13.14	0.14
3	CaO	3.94	0.48
4	Fe2O3	3.32	0.39
5	K2O	1.26	1.9
6	MgO	1.14	0.6
7	TiO2	0.5	-
8	Na2O	0.26	-
9	SO3	0.12	0.07
10	P2O5	0.09	0.9
11	MnO	0.05	0.09
12	ZrO2	0.05	-
13	SrO	0.01	-
14	ZnO	0.01	0.01
15	Rb2O	0.01	-
16	Cl	0.01	0.02
17	LOI	7.7	2.9

Table 4. Hydrated lime properties

Item	Formula	%
1	Ca(OH)2	94.62
2	SiO2	2.50
3	MgO	1.50
4	CaCo3	1.00
5	Fe2O	0.20
6	Al2O	0.10
7	SO3	0.05
8	Cl	0.01
9	Other metals	0.03

2.3. Laboratory tests

For the classification of the soil and mixtures, the ASTM criteria were applied, using sieve granulometry tests and finding Atterberg's limits. Natural soil is characterized as a sandy clay (CL) according to the unified soil classification system (USCS) with 50.9% fine material, LL 40%, PL 16%, and PI 24%, with an A-6(5) AASHTO classification.

The compaction characteristics were obtained through the Modified Proctor test performed on all samples. Natural soil parameters were a Maximum Dry Density (MDD) of 1,826 g/cm^3 and an Optimum Moisture Content (OMC) of 14.80%.

The soil resistance characteristics were evaluated through the California Bearing Ratio test. Natural soil showed a 4.50% CBR. The procedure was performed on all samples to analyze the fluctuations in the CBR caused by the addition of RHA.

3. Results and discussion

3.1. Soil performance

Analyzing the compaction results shown in figure 1, we can see how the addition of ash causes the soil to require more water to reach its MDD. The OMC increases from 14.80% to 19.60%, between the natural soil and the R22C3 sample respectively. In the sample R16C3 -of maximum CBR- the values of MDD and OMC are 1.58g/cm3 and 16.50% respectively, in contrast to the mixture R0C3, the soil density decreases and more humidity is required to reach an approximate CBR of 50% as shown in figure 2.

Regarding the mixture R28C3 with the rest of the combinations used, the MDD continues to decrease in a controlled manner, however, the OMC increases drastically to 25.10%, generating a decrease in the CBR to 32.90%.

Flocculation between alumina and silica molecules with the calcium hydroxide creates an increase in the resistance due to the reactions between the lime and the soil's silica. With more silica added by the RHA, more pozzolanic reactions are available to react but this doesn't improve the performance significantly. The OMC of the R28C3 sample is due to the excess of water accumulated by the ash that hasn't reacted at all.

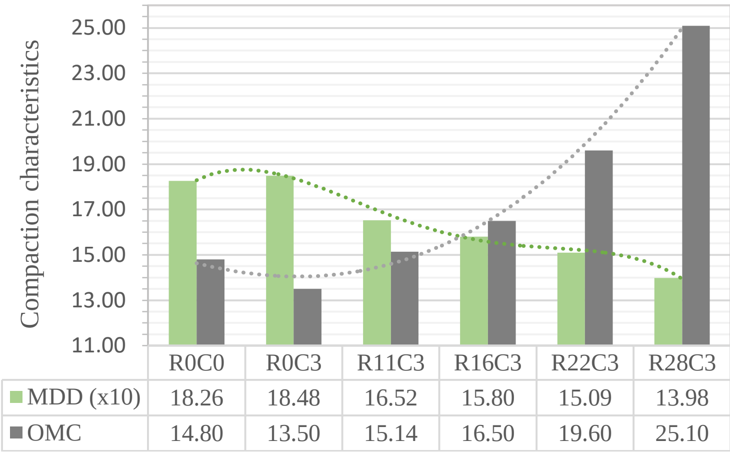

Figure 1. Effects of stabilizers on compaction parameters.

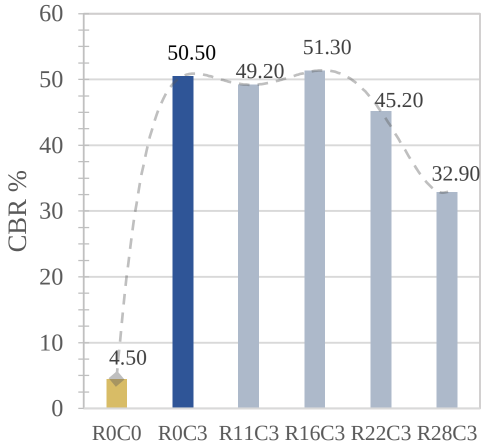

Figure 2. CBR of combinations.

3.2. Variation on Atterberg's limits

The results in figure 1 agree with the analysis of the limits shown in table 5. The R28C3 mixture shows an LL greater than 50%, which theoretically would be soil with high plasticity. However, it lacks on plasticity index and this is supported by the value of GI 0. The plasticity chart shown in figure 3 shows how the rest of the samples remain in the range of low plasticity soils.

The group index of the samples allows us to perform a more adequate analysis, showing that the soil tends to have thicker particles due to the ion exchange and the pozzolanic reactions that are caused by the additions.

Table 5. Atterberg's limits and soil classification

ID	LL	PL	PI	USCS	AASHTO
R0C0	40	16	24	CL	A-6 (5)
R0C3	40	25	15	CL	A-6 (3)
R11C3	43	31	12	ML	A-7-5 (2)
R16C3	46	33	13	ML	A-7-5 (2)
R22C3	46	NP*	NP*	ML	A-5 (0)
R28C3	67	NP*	NP*	MH	A-5 (0)

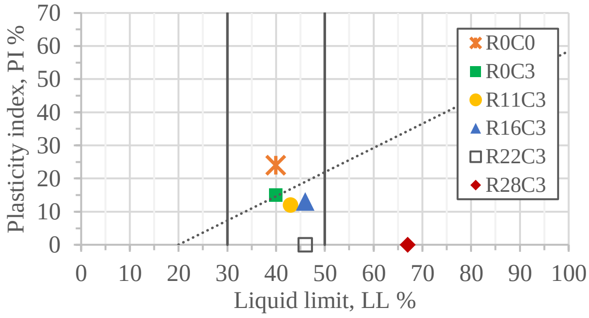

Figure 3. USCS plasticity chart.

4. Conclusions

The values of CBR decrease from the composition R16C3 onwards because the pozzolanic reactions between the CaO and the SiO_2 are stopped and the ash unreacted begins to remain in the internal structure of the compound. This goes side by side with the increase in OMC, since the ash absorbs more water, generating a gel that gives it resistance to the soil, but not as much as expected. The flocculation generated between the soil and lime generates an improvement of up to 11.2 times the value of the CBR at the beginning (R0C3) due to the internal restructuring that the soil and its silica-alumina compounds undergo. The addition of lime ash improves the durability of the soil and makes it easier to work by having more granular materials than at the beginning.

Consistency limits were 40% LL, 16% PL, 24% PI, resulting in a classification of sandy clay type A-6 (5) according to AASHTO. The GI decreases as more ash is added, indicating the low plasticity of the soil. The mineralogical analysis reflects that the clayey soil is rich in silica, so the addition of RHA does not imply a significant change in the SiO_2 percentage therefore, there was only a 1.55% improvement evidenced.

The MDD decreases from 1,826 g/cm^3 to 1,398 g/cm^3. On the other hand, the OMC increases from 14.80% to 25.10%, due to the flocculation generated by the addition of lime to the soil; The size of the nominal soil particles increases taking up more space and empty filling. At the same time, the pozzolanic reactions generated by the addition of rice husk ash cause the sample to absorb more water since this is essential for a pozzolanic reaction.

As well, the reduction in CBR from 22% of ash addition to the soil-lime combination demonstrates the absence of reactions and the excess ash remaining in the soil. However, pozzolanic reactions are progressive and improve over time, therefore the possibility is not ruled out that the CBR may improve in the future.

The results indicate that the ash has a low potential to be used as a stabilizer together with lime for silica-rich clay soils, since no improvement is demonstrated, on the contrary, the CBR decreases compared to the R0C3 combination. Even though, if resources are available, lime and ash can be used to decrease the permeability of the soil, giving it improved workability and generating its long duration for tropical climates where the soil is exposed to heavy rains.

In addition, the application of RHA in geotechnical projects adds value to this material, offering an environmentally appropriate destination for this type of waste. It is possible to carry out more tests with different dosages of lime especially evaluated in soils which percentage of material passing the mesh No. 200 is between 50%-40% since previous investigations have soil records with the presence of fines of up to 90%.

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