Influence of rice husk ash and lime on engineering properties clayey subgrade

Agus Muntohar
Universitas Muhammadiyah Yogyakarta

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Agus Setyo Muntohar
Civil Engineer, Soil Mechanics Laboratory Department of Civil Engineering, Muhammadiyah University of Yogyakarta, Indonesia.
Email :muntohar@umy.ac.id

Gendut Hantoro
Road Engineer, Department of Civil Engineering, Muhammadiyah University of Yogyakarta, Indonesia.

ABSTRACT

When geotechnical engineers are faced with clayey soils, the engineering properties of those soils may need to be improved to make them suitable for construction. Waste materials such as fly ash or pozzolanic materials have been used for soil improvement. Recent research, based on pozzolanic activity, found that rice husk ash was a potential material to be utilized for soil improvement. The effects of the engineering properties of clayey soils when blended with lime and rice husk ash are the focus of this paper. A series of laboratory experiments have been implemented. Varieties of samples were made by blending both rice husk ash and lime together. These samples were 2%, 4%, 6%, 8%, 10% and 12% for lime and 7.5%, 10% and 12.5% for rice husk ash. The results from the LHRA (lime-rice husk ash) blend confirmed that the blend would diminish swell behaviour of clayey soils. Their PI (plasticity index) would decrease from 41.25% to 0.96% when subjected to a LHRA blend of 12-12.5%. Their swell potential would decrease from 19.23% to 0.019% when subjected to the same blending as well. Their CBR (California Bearing Ratio) value would increase from 3.03% to 16.3% at a LHRA blend of 6-12.5%. Their internal friction angle concerning shear strength parameters would enhance from 5.36 to 23.85. Soil cohesion increased as well from 54.32 kN/m2 to 157.19 kN/m2. Increasing the shear parameter caused bearing capacity to be 4131 kN/m2 from 391.12 kN/m2. At LHRA 6-10%, consolidation settlement was lowered from 0.03 to 0.006. All of these factors can be summarized to say that by blending lime-rice husk ash together, you may enhance the engineering properties of clayey soils. This is advantageous for work construction in the civil engineering field..

KEYWORDS: engineering properties, lime-rice husk ash, clay.

INTRODUCTION

A difficult problem in civil engineering work exists when the sub-grade is found to be expansive clay. Soils having high clay content have a tendency to swell when their moisture content is allowed to increase (Chen, 1981). This moisture may come from rains, floods, or leaking water from water or sewer lines or from the reduction of surface evaporation when an area is covered by a building or pavement. Frequently, these clayey soils cause the cracking and breaking up of pavements, railways, highway embankments, roadways, foundations and channel or reservoir linings (Cokca 1997).

Generally, in Indonesia, soils are covered with greater than 50% lateritic soil. This soil generally is tendency having high swell potential and was not favourable when is used for construction. Construction damages are possible occurred (Munirwansyah, 1989). When geotechnical engineers are faced with that problem, a need for improving the engineering properties of the soil is justified. Fly ash or pozzolanic materials, which are regarded as wastes, may be used as stabilizing agent in term of soil improvements. Recent research, based on pozzolanic activity, found that rice husk ash was a potential material for soil improvement (Muntohar 1997 and 1999). The effect of rice husk and lime on the engineering properties of clayey soils is the focus of this paper.

THEORY

SOIL STABILIZATION

When the mechanical stability of a soil cannot be obtained by combining materials, it may be advisable to order stabilization by the addition of cement, lime, bituminous material or special additives. Cement treatment is most applied to road stabilization especially when the moisture content of the sub-grade is very high. Lime or waste is also sometimes applied for stabilization.

Calcium hydroxide (*slaked lime*) is most widely used for stabilization. *Calcium oxide* (*quick lime*) may be more effective in some cases, however. The *quick lime* will corrosively attack equipment and may cause severe skin burns to personnel. Ingles (1972) recommended the criteria of lime mixture as show in Table I.

Table I. *Suggested lime contents*

Soil type	Content for modification	Content for Stabilization
Fine crushed rock	2 – 4 percent	Not recommended
Well graded clay gravels	1 – 3 percent	~ 3 percent
Sands	Not recommended	Not recommended
Sandy clay	Not recommended	~ 5 percent
Silty clay	1 – 3 percent	2 – 4 percent
Heavy clay	1 – 3 percent	3 – 8 percent
Very heavy clay	1 – 3 percent	3 – 8 percent
Organic soils	Not recommended	Not recommended

Rice husk ash (RHA) is a *pozzolanic material* that could be potentially used in Indonesia, considering it is sufficiently produced and is widespread. When rice husk was allowed to burn under controlled temperature, higher pozzolanic properties (than other leaf plants) were observed. *Silica* is a main mineral of RHA. When reacted with lime, it will form a bonded gel [$Ca(SiO_3)$]. The composition of RHA minerals is show in Table II.

Table II. *Composition of RHA minerals (*Wen-Hwei, 1986*)*

Mineral	Composition (%)
SiO_2	86.90 - 97.30
K_2O	0.58 - 2.50
Na_2O	0.00 - 1.75
CaO	0.20 - 1.50
MgO	0.12 - 1.96
Fe_2O_3	~ 0.54
P_2O_5	0.2 – 2.85
SO_3	0.1 – 1.13
Cl	~ 0.42

REACTION MECHANISM OF POZZOLANIC MATERIALS

Lime reacts with any other fine pozzolanic component (such as hydrous silica and RHA minerals) to form calcium-silicate cement with soil particles. This reaction is also water insoluble. The cementing agents are exactly the same for ordinary Portland Cement. The difference is that the calcium silicate gel is formed from the hydration of anhydrous *calcium silicate* (cement), whereas with the lime, the gel is formed only by the removal of silica from the clay minerals of the soil. The pozzolanic process may be written as follow:

$Ca(OH)_2 + SiO_2 \rightarrow$ C-S-H
$Ca(OH)_2 + Al_2O_3 \rightarrow$ C-S-H
(Note: C-S-H is cemented material).

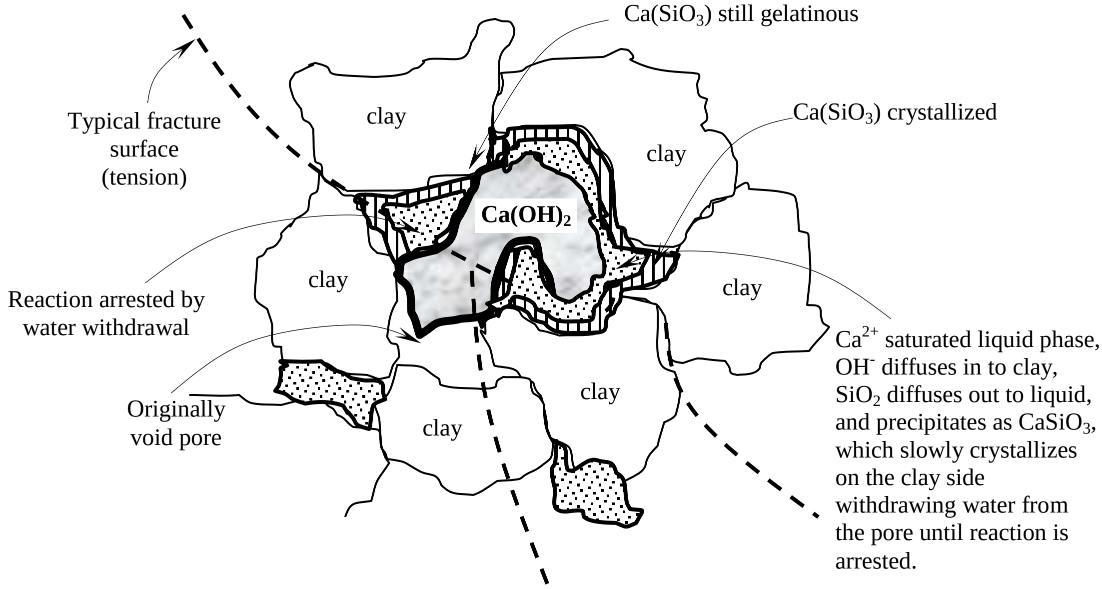


Figure 1. *Reaction mechanism of stabilization on clay soils (Ingles, 1972).*

The silicate gel proceeds immediately to coat and bind clay lumps in the soil and to block off the soil voids in the manner shown by Figure 1. In time, this gel gradually crystallizes into well-defined *calcium silicate hydrates* such as *tobermorite* and *hillebrandite*. The micro-crystals can also mechanically interlock. The reaction ceases on drying, and very dry soils will not react with lime or cement. The mechanism of the reaction can be represented below:

$NAS_4H + CH \rightarrow NH + CAS_4H$ + degradation product

$$\leftarrow NH + C_2SH^{*} \hookleftarrow \quad _{(2CH)}$$

Where: S = SiO_2, H = H_2O, A = Al_2O_3, C = CaO, N = Na_2O.
* As silica is progressively removed, calcium aluminates and alumina are formed residually
** Or CSH

METHOD

Material

The soils involved in this research were dug from a quarry area in Kasihan, Bantul. The soil sample was disturbed. Hydrated lime in powder form was used for the lime material.

Equipment

The tests such as consistency limits, grain-size distribution, compaction, California Bearing Ratio (CBR), consolidation and the triaxial test were carried out using standardized equipment as mentioned as in ASTM-1995. All of the tests were conducted in the Soil Mechanics Laboratory, Department of Civil Engineering, Muhammadiyah University of Yogyakarta.

Test Procedure

A series of laboratory experiments have been implemented. Various samples were made by blending both rice husk ash and lime together. These samples were 2%, 4%, 6%, 8%, 10% and 12% for lime and 7.5%, 10% and 12.5% for rice husk ash. The test procedure is described as follows:

1. Preparation of soil samples:
    - soil samples were dried,
    - soil samples sieved through #4 and #40 sieves
2. Mixing of soil samples:
    - soil samples blended with lime (with the defined percentage),
    - water added to act as a medium for the reaction process,
    - soil samples were cured.
3. Testing of soil samples:
    - consistency limits
    - grain size distribution
    - compaction
    - California Bearing Ratio
    - triaxial test
    - consolidation test

TEST RESULTS

Clay soils sample (no blending of LHRA)

The clay soil with no blending of LHRA was tested to examine its physical properties. Theses are shown in Table III. The chemical elements of the lime- rice husk ash are shown in Table IV.

Table III. *Physical characterization of clay sample*

Physical properties	Test result
Nature moisture content, w_N	71.38 %
Moisture content (disturbed)	18.32 %
Specific Gravity, Gs	2.63
Liquid Limits, LL	73.59 %
Plastic Limits, PL	32.34 %
Shrinkage Limits, SL	13.82 %
Plasticity Index	41.25 %
Maximum Dry Density, γ_d	1.32 gr/cm^3
Optimum Moisture Content	34 %
Grain size distribution:	
▪ Coarse particle	9.24 %
▪ Fine particle	90.76 %
▪ Clay	10.00 %
▪ Silt	80.76 %
Activity	3.059

Table IV. *Chemical element of tested materials*

Chemical elements	Clay (%)	RHA (%)	Hydrated Lime (%)
SiO_2	51.39	89.08	0.00
Al_2O_3	17.21	1.75	0.13
Fe_2O_3	9.33	0.78	0.08
CaO	3.66	1.29	59.03
MgO	1.17	0.64	0.25
Na_2O	1.72	0.85	0.05
K_2O	0.39	1.38	0.03
MnO	0.25	0.14	0.004
TiO_2	0.98	0.00	0.00
P_2O_5	0.17	0.61	0.00
H_2O	4.23	1.33	0.04
LOI	9.48	2.05	40.33

LOI : Loss on Ignition

Engineering Properties

The results of the engineering property tests on the soil are as shown in Table V.

DISCUSSION

Based on a series of these tests, the soil is classified as *Silty Clay* (Gs = 2.632 with 90.76% fines) which is tendency having expansive behavior. Chen (1975) classified soil with PI > 35% as having very high swell potential. The LL and PI of the soil samples are respectively 73.59% and 41.25%. The effect of blended lime and rice husk ash (LRHA) on the physical properties of soil can be shown as in Figure 2 and Figure 3.

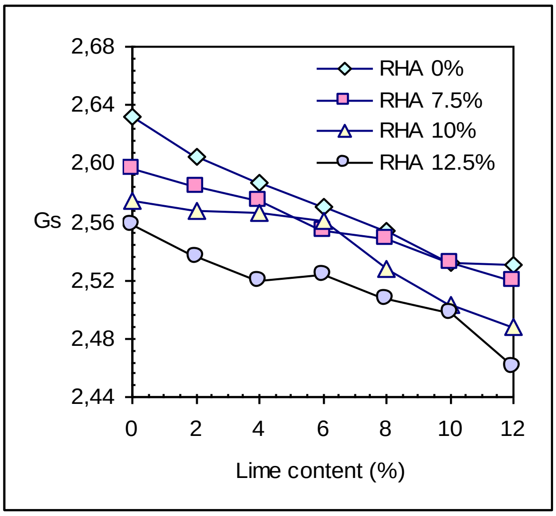
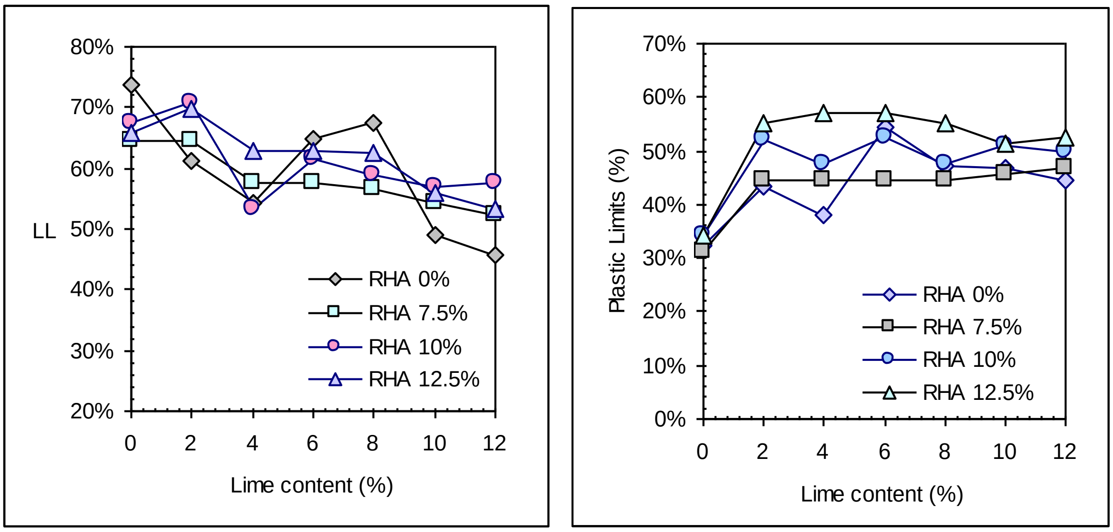
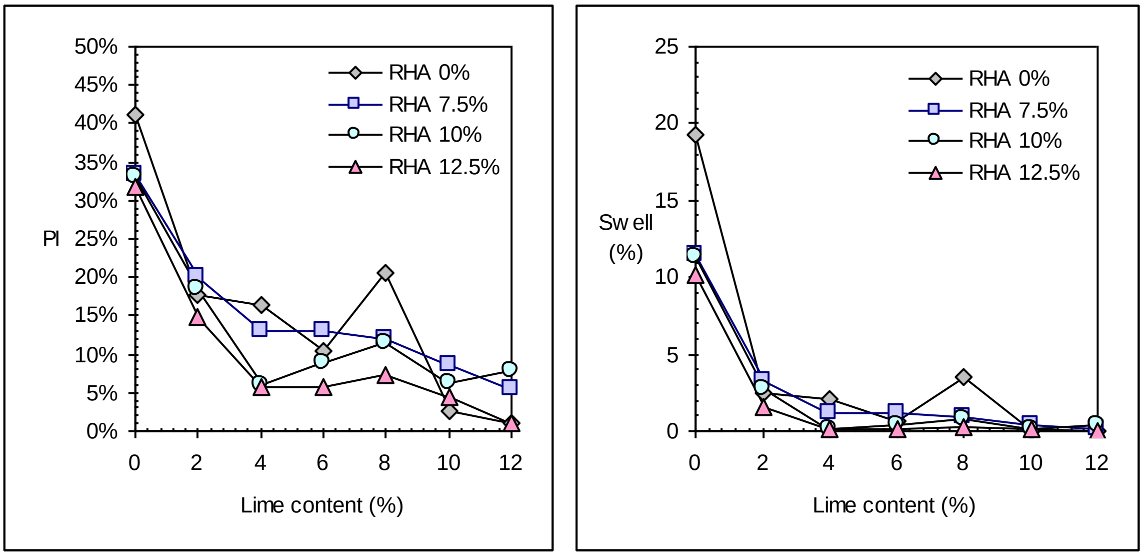


Figure 2. *Effect of blended LRHA on the specific gravity of soil*

As shown in Figure 2, adding LRHA decreases the specific gravity of the soil. This indicates that the soil is lighter than its origin conditions (unstabilised). Figure 3 shows the influence of LRHA on the consistency limits. Figure 3(c) shows that the PI of the soil decreases corresponds to increase in lime content. Figure 3(d) indicates that swell potential decreases as well. Chen (1975) presented the correlation of PI with swell potential. The swell potential is higher for higher PI. The lowest value was attained at a 12.5% LRHA. Figure 4(a) and (b) show that there is a decrease in finer particles by addition of lime and RHA.



(a) (b)



(c) (d)

Figure 3. *Influence of LRHA on the consistency limits (a) Liquid limits (LL), (b) plastic limits (PL), (c) Plasticity index (PI), (d) Swell potential.*

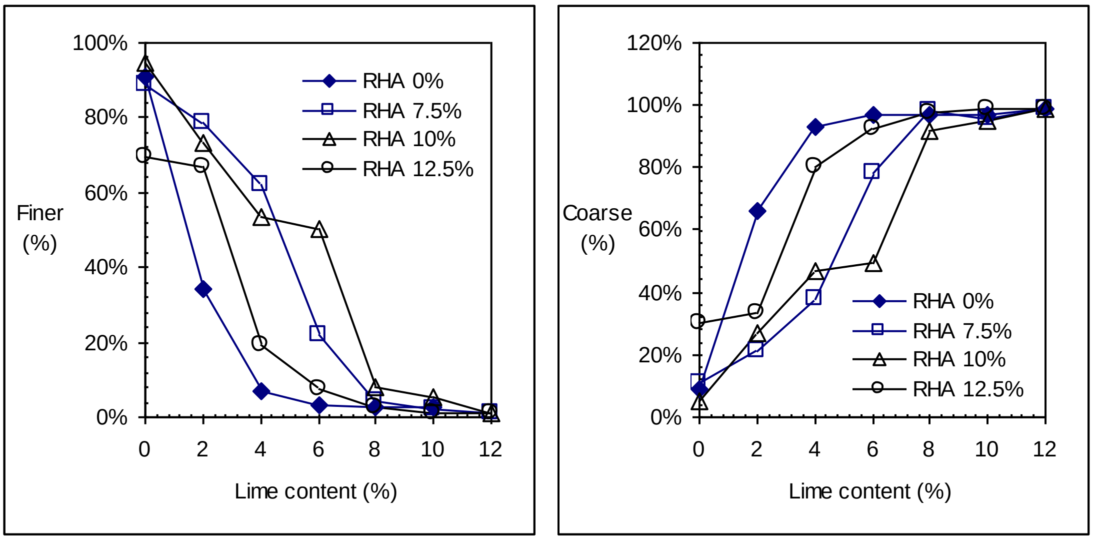
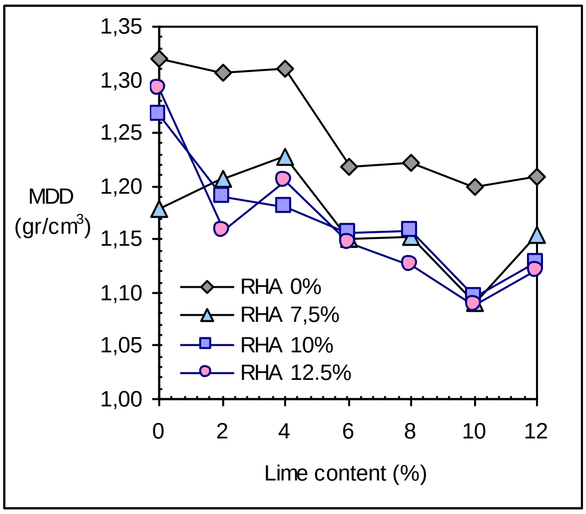
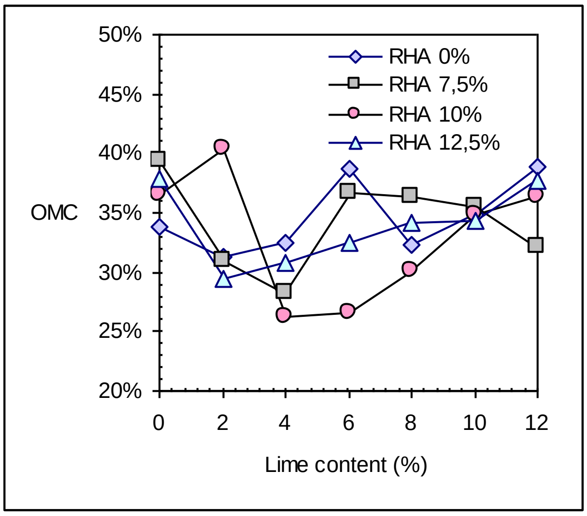


Figure 4. *Effect of LRHA on the grain sieve of clayey soil (a) Finer particle, (b) Coarse particle.*





(a) *(b)*

Figure 5. *Influence of LRHA on compaction of clayey soil, (a) Maximum dry density (MDD)(b) Optimum water content (OMC)*

Figure 5 depicts that by increasing lime and RHA content in soil, MDD tends to decrease, whereas OMC increases. Decreasing MDD indicates that compaction energy (CE) is less than the origin state. Increasing OMC tends to be prevalent when lime was added. Figure 6 shows that soil, which has been blended with lime, is best to be compacted in the wet optimum state. Therefore, blended LRHA has a place in construction work where a soil's moisture content is very high. Ordinarily, a soil with high moisture content can be combined with Portland cement (*a cement stabilizer*). Utilizing the blend of LHRA makes the cost decrease, for example: Price of Portland cement is Rp500.00 per kg; price of LRHA is Rp.125 per kg (Lime Rp125 per kg and Rice Husk Ash Rp20 per kg). Assuming the weight of soil is 1 kg, and a mixture of 2-10% LHRA, the cost is Rp4.50. When 2% cement is used, the cost is Rp10.00. The LHRA blend is found to be 45% cheaper that that of Portland cement.

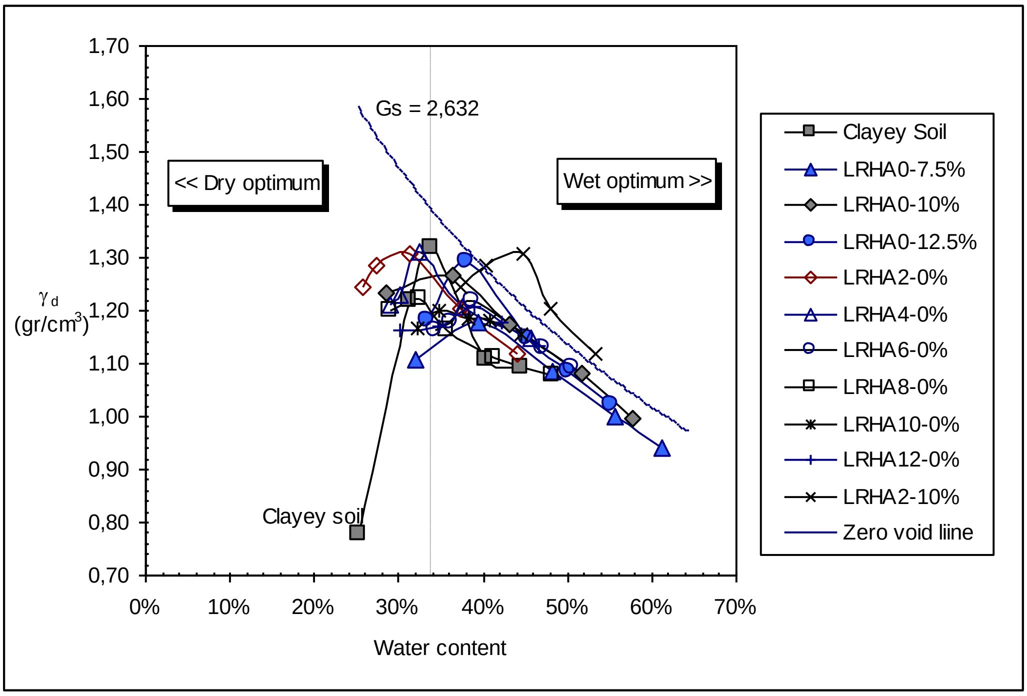
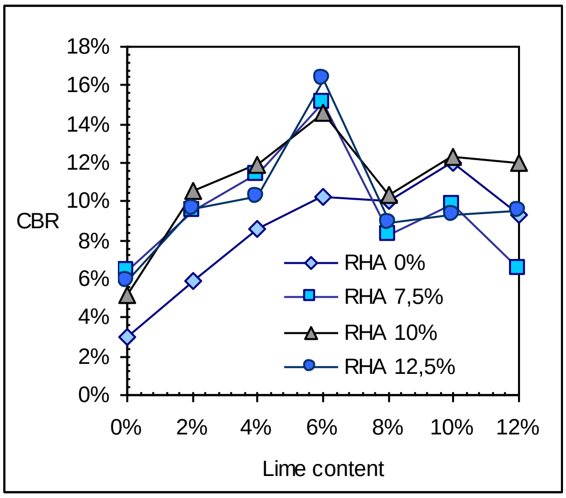


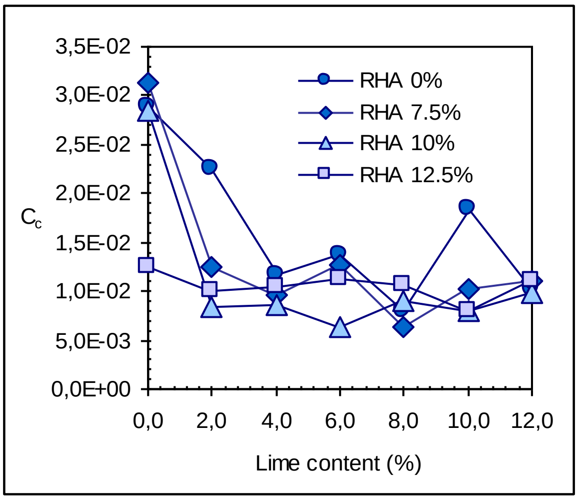
Figure 6. *Compaction characterization of clayey soil with blended by LRHA.*

Table V. Engineering properties of sample with several blending

Admixture Mixing		Atterberg limits			Specific Gravity	Grain size		Compaction		CBR	Triaxial		Consolidation
Lime	RHA	LL (%)	PL (%)	PI (%)	Gs	Coarse (%)	Finer (%)	MDD gr/cm^3	OMC (%)	(%)	c, kPa	□, °	Cc
0%	0%	73.59	32.34	41.25	2.632	9,24	90,76	1.32	34	3.03	54.32	5.36	2.88E-02
	7.50%	64.53	31.22	33.31	2.596	11,19	88,81	1.18	39.4	6.39	52.87	8.24	3.12E-02
	10%	67.46	34.29	33.17	2.574	5,29	94,71	1.27	36.5	5.18	53.22	9.94	2.85E-02
	12.50%	65.96	34.17	31.79	2.559	30,23	69,77	1.29	37.94	5.86	57.6	5.65	1.26E-02
2%	0%	61.22	43.42	17.8	2.604	66	34,00	1.31	31.28	5.9	61.59	13.07	2.26E-02
	7.50%	64.46	44.51	19.95	2.585	21,23	78,77	1.21	31.01	9.47	58.24	13.71	1.25E-02
	10%	70.88	52.29	18.59	2.567	26,89	73,11	1.19	40.42	10.57	57.38	14.42	8.34E-03
	12.50%	69.75	54.99	14.75	2.536	33,2	66,80	1.16	29.44	9.63	57.6	13.24	1.00E-02
4%	0%	54.36	37.91	16.44	2.586	93,26	6,74	1.31	32.39	8.55	48.22	9.89	1.18E-02
	7.50%	57.44	44.51	12.93	2.575	37,95	62,05	1.23	28.21	11.39	46.79	12.16	9.52E-03
	10%	53.37	47.5	5.87	2.566	46,6	53,40	1.18	26.29	11.89	42.91	12.45	8.64E-03
	12.50%	62.91	57.18	5.73	2.524	80,5	19,50	1.21	30.74	10.22	40.81	13.11	1.05E-02
6%	0%	64.74	54.24	10.5	2.571	96,93	3,07	1.22	38.75	10.22	54.8	9.85	1.37E-02
	7.50%	57.44	44.51	12.93	2.553	78,2	21,80	1.15	36.7	15.13	52.18	10.78	1.28E-02
	10%	61.56	52.68	8.88	2.56	49,5	50,50	1.16	26.51	14.54	59.21	15.14	6.30E-03
	12.50%	62.91	57.18	5.73	2.524	96,65	3,35	1.15	32.5	16.3	53.54	21.63	1.13E-02
8%	0%	67.56	47.02	20.54	2.553	97,21	2,79	1.22	32.37	10.07	97.74	14.84	8.08E-03
	7.50%	56.45	44.51	11.94	2.548	95,63	4,37	1.15	36.27	8.3	100.25	13.67	6.42E-03
	10%	58.99	47.62	11.36	2.528	92,05	7,95	1.16	30.19	10.35	109.22	14.2	9.02E-03
	12.50%	62.69	55.29	7.4	2.507	97.38	2.62	1.13	34.22	8.92	96.24	22.81	1.07E-02
10%	0%	49.16	46.64	2.52	2.532	97.2	2.8	1.2	34.83	12	124.31	14.32	1.84E-02
	7.50%	54.35	45.77	8.58	2.532	97.95	2.05	1.09	35.58	9.87	127.76	12.89	1.02E-02
	10%	56.94	50.82	6.13	2.503	94.69	5.31	1.1	34.9	12.33	157.19	23.85	7.98E-03
	12.50%	56.05	51.52	4.53	2.497	98.67	1.33	1.09	34.33	9.36	128.14	24.51	7.97E-03
12%	0%	45.57	44.51	1.06	2.531	98.85	1.15	1.21	38.85	9.27	115.64	8.11	1.03E-02
	7.50%	52.25	46.8	5.45	2.52	98.84	1.16	1.15	32.16	6.48	124.51	11.84	1.11E-02
	10%	57.59	49.82	7.78	2.488	99.13	0.87	1.13	36.36	12	135.74	12.8	9.91E-03
	12.50%	53.33	52.37	0.96	2.46	98.84	1.16	1.12	37.77	9.54	117.71	21.03	1.10E-02

Figure 7(a) reveals a trend to enhance and attain the optimum CBR value at a 6% lime content and a 6-12.5% maximum of rice husk ash (RHA). Figure 7(b) shows the compressibility index (Cc) tends to be non-linear. This condition exhibits that when the rate of consolidation is rapid, the settlement of the soil will reduce. Figure 8 shows that the addition of lime augments the shear strength parameter, cohesion, and the internal angle of friction. Lime dominated the cohesion properties of the soil, whereas RHA interferes with the internal angle of friction. Furthermore, the soil strength is enhanced. Figure 8(c) shows that the maximum ultimate strength is attained at a 10% LHRA content. Figure 9 shows brittle behavior of the soil when mixed with LHRA. Therefore, it can be concluded that lime and rice husk ash (LRHA) can improve the engineering properties of soils. Practically, the effective lime content should be blended in the range of 6-10%.





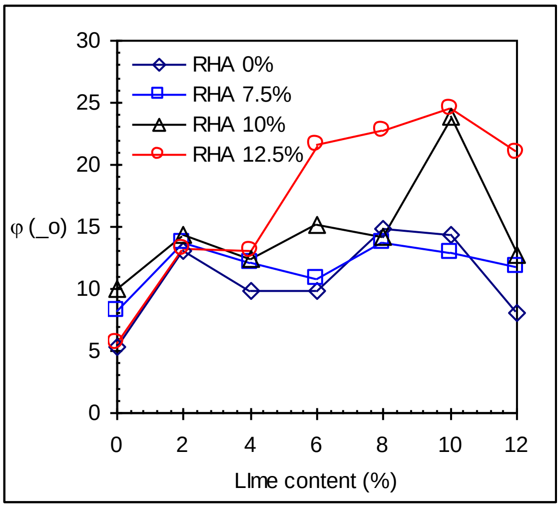
(a) *(b)*

Figure 7. *California bearing ratio (CBR laboratory) and consolidation parameter of soil with blended by LRHA (a) CBR laboratory (b) Compressibility Index (Cc)*

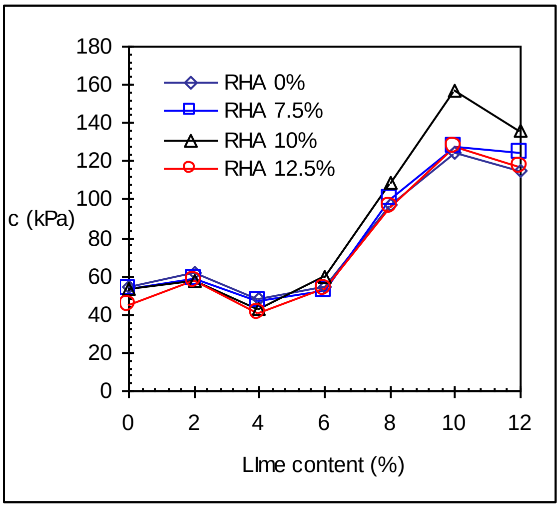
CONCLUSION

Lime stabilization is commonly used for clayey soil. This research shows:

1. Physical properties such as consistency limits and swell potential exhibit improvements when mixed with the appropriate LHRA blend.
2. LRHA stabilization is more advantageous when moisture content of soil in the field is very high or applied in the optimum condition.
3. The engineering properties of soil improve:
   a) CBR, and shear strength of soil improve at a lime range of 6 - 10%
   b) Consolidation settlement diminishes
   c) Rate of consolidation enhances by increasing of LRHA.
4. Economically, utilization of LRHA for geotechnical applications is cheaper.



(a)



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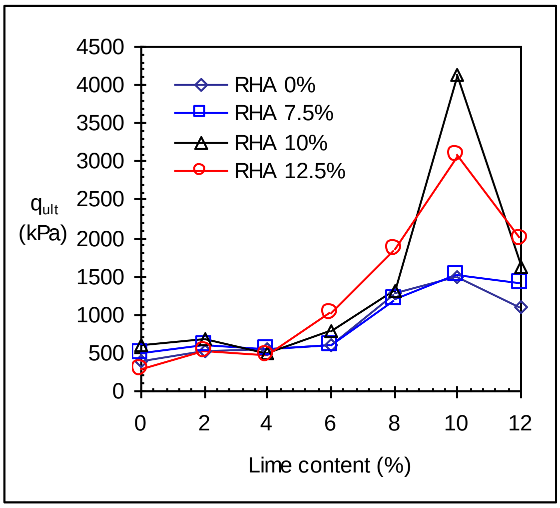

(c)

Figure 8. *Effect of LRHA on the shear strength of clayey soil(a) Shear strength of soil ($q_{ultimate}$) (b) Internal friction angle (φ) (c) Cohesion*

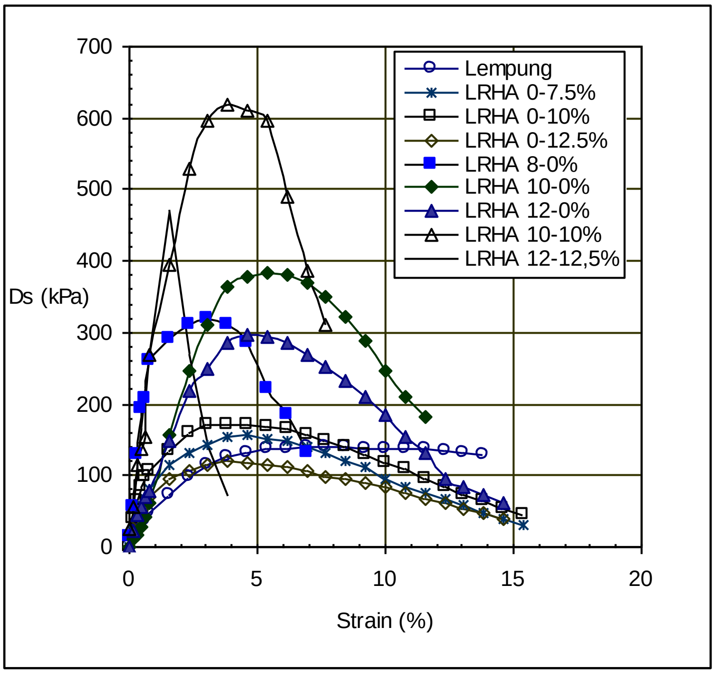

Figure 9. *Stress-strain behaviour of clayey soil under Triaxial test.*

ACKNOWLEDGEMENT

The support provided by Soil Mechanic Laboratory during this project is appreciated. The author thankful to the assistant Sri Atmaja, Muhammad Huzairi, Isman Suhadi, Bambang Ariwibowo, et al.

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