Front. Earth Sci. China 2010, 4(4): 471–480
DOI 10.1007/s11707-010-0138-x

RESEARCH ARTICLE

Influence of using rice husk ash in soil stabilization method with lime

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Abstract In clayey lands, swelling problem causes vertical displacements on road subbase, and finally, failure in pavement occurs due to lack of appropriate drainage systems. One popular and inexpensive method of soil stabilization is using lime. Investigations indicate that based on environmental and atmospheric conditions, the chemical reaction of lime and clayey soil is not accomplished well, owning to low temperature and high humidity. This paper aims to investigate the influence of adding rice husk ash on the reaction between soil and lime and lime reaction and determine soil physical and mechanical characteristics. Therefore, sufficient laboratory soil tests, such as Atterberg limits, compaction, California bearing ratio (CBR), and direct shear test are carried out, and the results are analyzed. The results generally indicate that adding lime and rice husk ash (RHA) causes a decrease in dry density and an increase in optimum water content. Increasing lime and RHA causes a decreasing rate in soil liquid limit and plastic limit. Adding lime and RHA to the soil causes a decrease in deformability of soil samples and gives more brittle materials. Also, this action causes an increase in shear strength. Moreover, increasing in CBR amount under the influence of increasing RHA is one of the main results of this paper.

Keywords rice husk ash (RHA), lime, soil laboratory tests, additives, soil stabilization

1 Introduction

Different methods of soil improvement are interesting to geotechnical engineers. Some nonstructural methods are seriously investigated recently. For example, effects of using compost on optimizing parsley production and also implicitly on sandy soil properties are investigated by Mylavarapu and Zinati (2009). The effect of electro-osmosis with injection of saline solutions on silty clay has been studied by Chang et al. (2009) and results indicate that the average undrained shear strength of the soil gradually improves with electro-osmosis passing days. Moreover, the influence of using lime piles on the improvement of bearing capacity and failing slope stabilization of clay soils is investigated by Rogers and Glendinning (1997).

In road construction projects, soil or gravelly material is used as the road main body in pavement layers. To have required strength against tensile stresses and strains spectrum, the soil used for constructing pavement should have special specification. One of the suitable methods to achieve these aims is using lime. Since 1945, the technique of soil treatment with lime has been in use. In fact, the reaction between soil and lime is performed very slowly. Therefore, activating the reaction of soil with lime by some additive is necessary. Rice husk is an agricultural waste obtained from rice milling. About 108 tons of rice husks are generated annually in the world (Alhassan, 2008). Rice husk ash (RHA) includes a huge amount of silica with high specific surface that is very suitable for activating the reaction of soil and lime. This matter is not suitable for cattle feeding and is nonbiodegradable. Thus, using RHA as an additive seems to be economical particularly in regions having high production capacity.

Over time, cement and lime are the two main materials used for stabilizing soils. These materials have rapidly increased in price due to the sharp increase in the cost of energy since 1970s (Neville, 2000). This has recently

Received February 15, 2010; accepted May 15, 2010

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motivated researches (among others, Lazaro and Moh, 1970; Rahman, 1987; Noor et al., 1990; Haji Ali et al., 1992; Mehta, 1992; Balasubramaniam et al., 1999; Muntohar and Hantoro, 2000; Muntohar and Hashim, 2002; Basha et al., 2004; Muntohar, 2004; Mustapha and Alhassan, 2005; Oyetola and Abdullahi, 2006; Jha and Gill, 2006) with the aim to find possible alternative soil stabilizing materials, especially those that are locally available and less costly, and their investigations revealed that RHA is a superior inexpensive material to further the geotechnical properties of soils. The effects of the ash on the soil-lime mixtures were investigated with respect to unconfined compressive strength (UCS) and coefficient of permeability by Alhassan (2008), and the results show that the UCS of the specimens increased with increasing RHA content at specified lime contents to their maximum values at 6% RHA. Moreover, Muntohar (2004) shows that the addition of 6% lime in combination with RHA principally has a significant effect on reducing swell and swelling pressure and increase the durability of soils. The influences of different mix proportions of cement and RHA on compaction characteristics, soaked and unsoaked unconfined compressive strength, tensile strength, and durability were studied by Noor et al. (1990), and the results show that RHA usage achieved satisfying values for soil strength. Also, stabilizing agents, such as cement and lime, were used by Haji Ali et al. (1992) in order to evaluate the effectiveness of them on engineering properties, such as Atterburg limits and compaction compression test, and results show that lime is a more effective stabilizing agent.

The aim of this paper is to investigate the influence of adding RHA on the reaction of soil and lime and estimate soil strength. For this reason, sufficient laboratory soil tests, such as Atterberg limits, compaction, California bearing ratio (CBR), and direct shear test are carried out, and the results are analyzed.

2 Laboratory studies

2.1 Soil specifications

Generally, fine-grained soil, such as silty clay, is selected for the investigations of this paper. The soil color is reddish yellow, and in the temperature of 20 centigrade, it trends to red. Technical specifications of the soil are shown in Tables 1 and 2. According to AASHTO soil classification method, the soil is classified as A-4, and according to unified system, it is named ML (silt with low plasticity).

2.2 Physical and chemical characteristics of RHA

To produce RHA, a cylindrical furnace, 60 cm in diameter and 1.2 m in height, is used. To enter oxygen, there are some openings 3 cm in diameter and 20 cm spacing in the 80 cm upper part of the furnace. The end part of the furnace is closed, and the 40 cm from the end part of it has no openings in order to prevent loss of produced ash.

The average temperature of the furnace during burn is about 550°C, and the duration of burning is 1.5 h. Whereas, based on Nair et al. (2007) investigations, the highest amounts of amorphous silica occur in samples burnt in the range of 500°C–700°C. To fix the temperature of furnace during burning period, the matters need mixing. After the completion of burning, it is necessary to expose the ash to air for cooling and completing the burning process. Figure 1 shows a sample of produced RHA.

According to the results of chemical tests shown in Table 3, produced RHA includes 83.7% silica. It means that the ash is approximately net silica. Therefore, it can cause a pozzolan action between soil and lime. Moreover, physical characteristics of produced ash are shown in Table 4.

It seems that burning different types of rice husk results in ash with similar physical and chemical specifications. In this investigation, the rice husk of Tarom has been burned under a controlled temperature and concludes a white ash including black bits with specific gravity of 1.827 (G_s = 1.827).

2.3 Characteristics of lime

The type of used lime type is slaked lime and some characteristics of that are shown in Table 5. Specifications of used lime are generally similar to one used in O'Flaherty's (1974) investigations.

2.4 Mix designs

Applied mix designs in this investigation and related indexes are summarized in Table 6.

Table 1 Technical specifications of investigated soil

pH	Shrinkage limit/%	Plasticity index/%	Plastic limit/%	Liquid limit/%	Specific gravity (G_s)
6.5	19	8	21	29	2.79

Table 2 Chemical analysis of investigated soil /%

Parameter	Cl	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
Amount	0.01	2	8	7	15	55

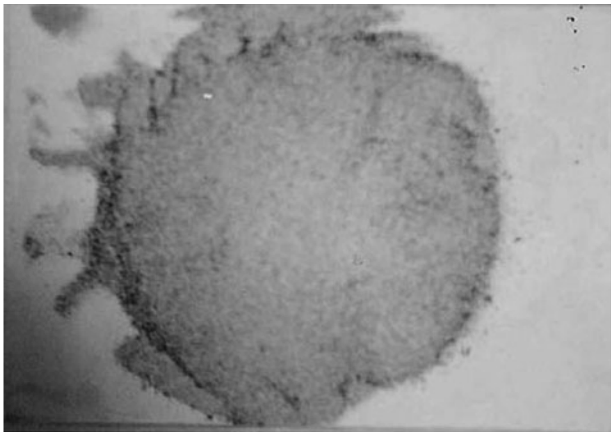

Fig. 1 Produced RHA

Table 3 Chemical characteristics of produced ash/%

Parameter	$P/(\times 10^{-6})$	$Mg^{2+}/(\times 10^{-6})$	$Ca^{2+}/(\times 10^{-6})$	$K/(\times 10^{-6})$	$Na/(\times 10^{-6})$	$SiO_2/(\times 10^{-6})$
Amount	24.7	66.1	0.016	0.124	0.114	83.7

Table 4 Physical characteristics of produced ash

Parameter	Density/$(kg\cdot m^{-3})$	Matter size/μm	Special surface/$(m^2\cdot g^{-1})$
Amount	2000–2300	4.8–8.9	60–130

Table 5 Characteristics of used lime

Matter	Non hydrated cao	Non hydrated mgo	CO_2	$Ca(OH)_2$
Percent	1.71	0.8	0	93.69

Table 6 Investigated mixtures and mentioned indexes

Index	Mix design
S	Soil without additive
S + 4L	Soil + 4% lime
S + 4L + 3R	Soil + 4% lime + 3% ash
S + 4L + 5R	Soil + 4% lime + 5% ash
S + 4L + 7R	Soil + 4% lime + 7% ash
S + 6L + 3R	Soil + 6% lime + 3% ash
S + 6L + 5R	Soil + 6% lime + 5% ash
S + 6L + 7R	Soil + 6% lime + 7% ash

2.5 Applied tests

To determine the influence of lime and RHA percentage on physical and mechanical specification of soil, some laboratory tests are used, such as Atterberg limits, direct shear test, CBR, and compaction test based on standards ASTM D4318-05 (2002), ASTM D3080-04 (2002), ASTM D1883-07 (2002), ASTM D0698-07E01 (2002), and AASHTO M145 (1986).

To conduct direct shear tests, saturated samples are made by submerging into water. Samples submerged into water about 24 h are new samples, and these ones staying more than 24 h are known old samples. Furthermore, CBR samples are saturated for about 4 d.

3 Laboratory test results

3.1 Influence of RHA and lime on maximum dry density and optimum water content

The quality of maximum dry density and optimum water content parameters of the soil are respectively 1.86 ton/m^3 and 14.9%.

As shown in Fig. 2, maximum dry density of soil decreases gradually with an increase in the percent of lime because specific gravity of lime is less than the soil. (The amount of specific gravity of lime and the soil are respectively 2.2 and 2.79 g/cm^3). On the other hand, lime initial setting causes a reduction in compressibility reduction of the soil. This trend is in agreement with findings by Osinubi (1998), Marks and Haliburton (1970), Ladd et al. (1960), and Alhassan (2008). Adding lime to the soil increases the amount of optimum water content that conforms the findings of Ola (1983), Osula (1991), and Alhassan (2008). The reason advanced is that the increased desire for water is somewhat commensurate to the increasing amount of lime, as more water is needed for the dissociation of lime into Ca and OH ions to supply more Ca ions for the cation exchange reaction.

Adding RHA to the soil causes a decrease in maximum dry specific gravity because the specific gravity of RHA is about 1.827 g/cm^3, so it is lighter than the combination of soil and lime (Fig. 2), and this trend is in agreement with Alhassan (2008).

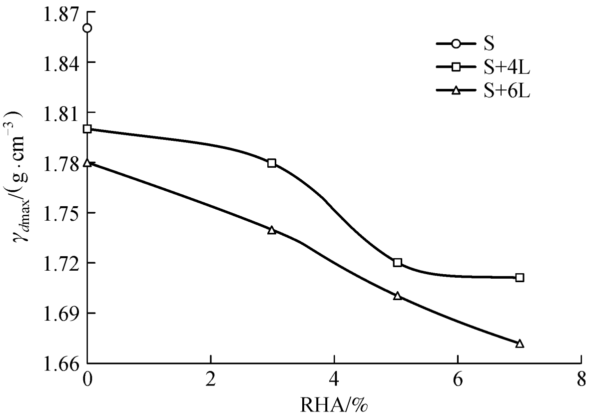

Fig. 2 Influence of RHA on maximum specific gravity

By adding RHA to the combination of soil and lime, optimum water content increases (Fig. 3), and this trend is in agreement with Alhassan (2008). The reason is an increase in the pozzolan reaction of soil and lime in initial hours and the need for extra water.

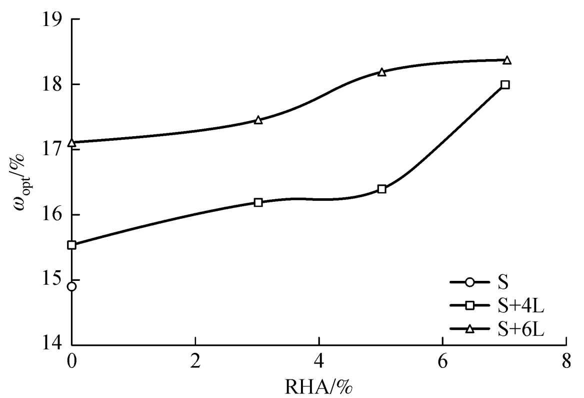

Fig. 3 Influence of RHA on optimum water content parameter

3.2 Influence of RHA and lime on liquid limit

According to that in Fig. 4. adding lime to the soil causes an increase in liquid limit parameter. Moreover, adding RHA to the soil increases liquid limit parameter, but this increasing effect is not as much as the influence of lime. The reason is the increase in the reaction velocity of the soil and lime and the need for extra water.

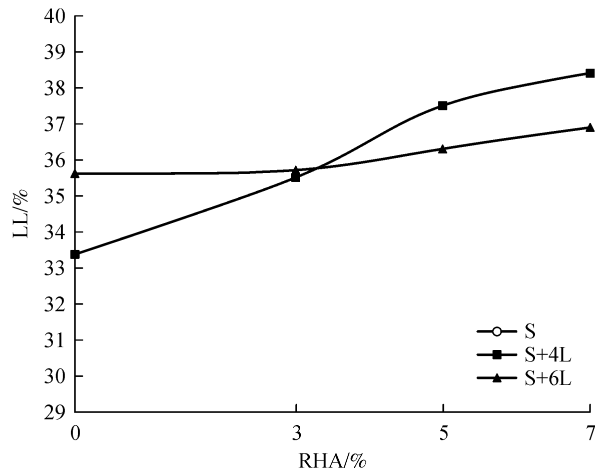

Fig. 4 Influence of RHA and lime on liquid limit parameter

3.3 Influence of RHA and lime on plastic limit

According to that in Fig. 5, adding lime and RHA to the soil causes an increase in plastic limit quality.

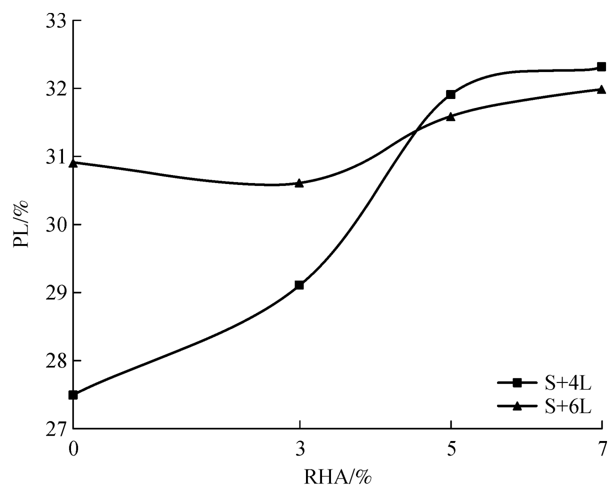

Fig. 5 Influence of RHA and lime on plastic limit parameter

3.4 Influence of RHA and lime on plasticity index

As shown in Fig. 6, generally, an increase in lime percent causes a decrease in plasticity index quantity. Moreover, the combination of soil and lime shows fluctuating trend by increasing RHA percent up to 7%.

3.5 Influence of RHA and lime on shear strength

3.5.1 0-d samples

By Adding RHA to the soil, a decrease in deformability of

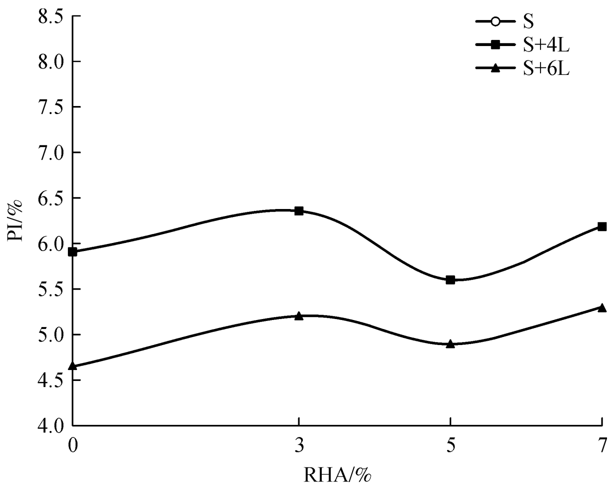

Fig. 6 Influence of RHA and lime on plasticity index parameter

the 0-d and 28-d soil samples occurs because RHA increases pozzolan reaction velocity of the soil and causes more brittle material. Stress-strain curves of 0-d samples with different normal loads are shown in Figs. 7–9.

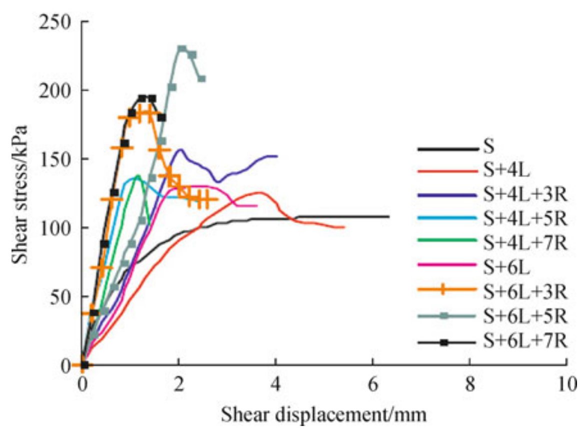

Fig. 7 Stress-strain curves of 0-d samples with normal load equal to 100 kPa

As shown in Figs. 10 and 11, adding lime to the soil causes an increase in cohesion and internal friction angle parameters. The reason is that the cementation of soil matters increases. Generally, adding RHA into the combination of soil and lime causes an increase in soil internal parameters and then causes a decrease in this trend.

3.5.2 28-d samples

The results of 28-d samples show that adding RHA to the different combinations of soil causes an increase in inclination of stress-strain curve. This means that, in this situation, combination of soil and lime gives more brittle matters that conclude elastic behavior. Stress-strain curves

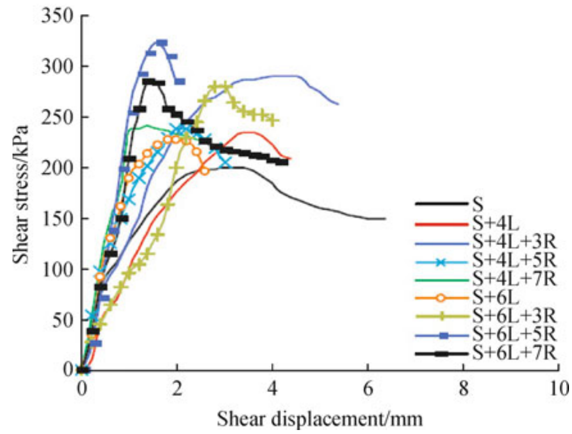

Fig. 8 Stress-strain curves of 0-d samples with normal load equal to 200 kPa

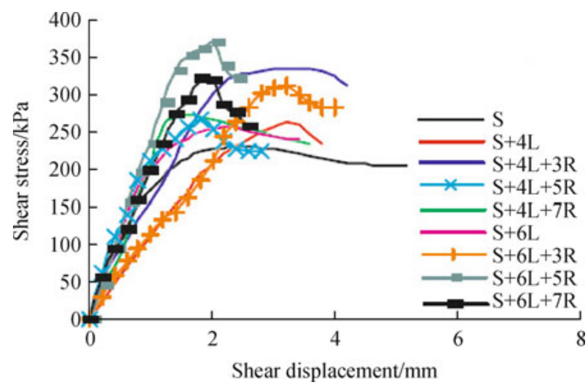

Fig. 9 Stress-strain curves of 0-d samples with normal load equal to 300 kPa

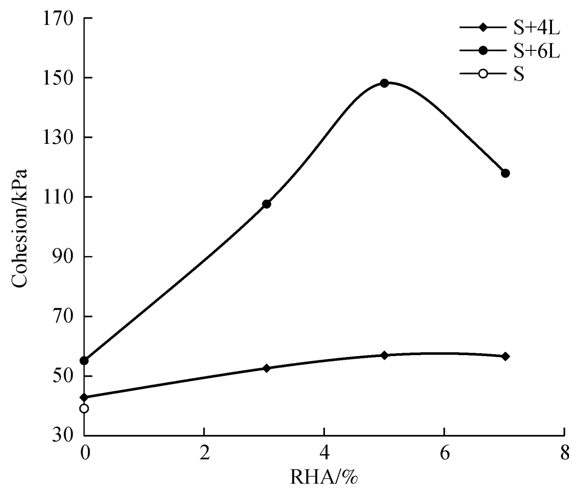

Fig. 10 Influence of lime and RHA on cohesion parameter of 0-d samples

of 28-d samples with different normal loads are shown in Figs. 12–14.

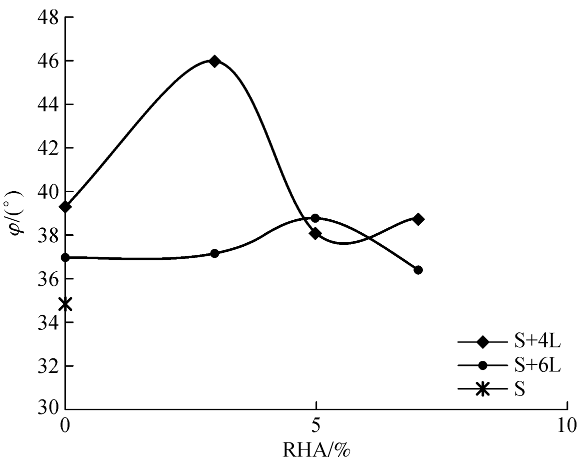

Fig. 11 Influence of lime and RHA on internal friction angle parameter of 0-d samples

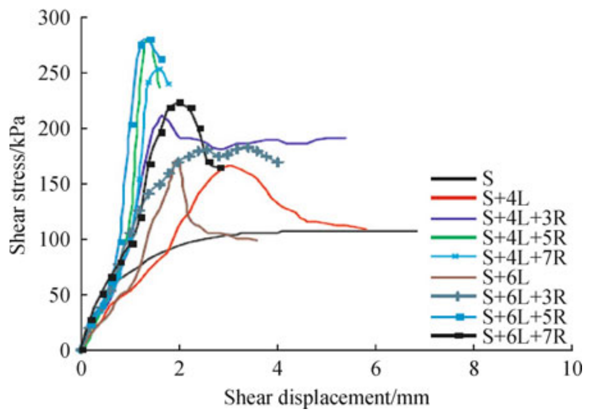

Fig. 12 Stress-strain curves of 28-d samples with normal load equal to 100 kPa

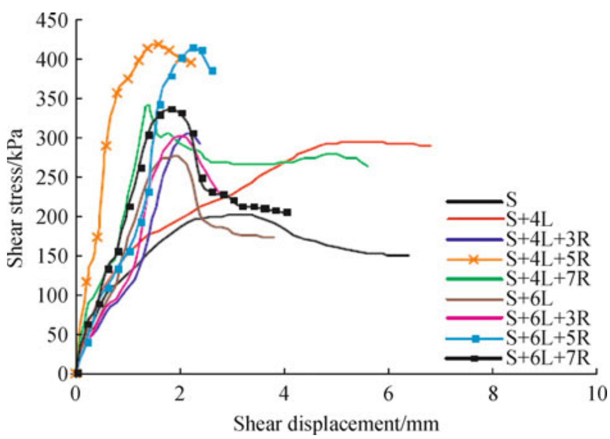

Fig. 13 Stress-strain curves of 28-d samples with normal load equal to 200 kPa

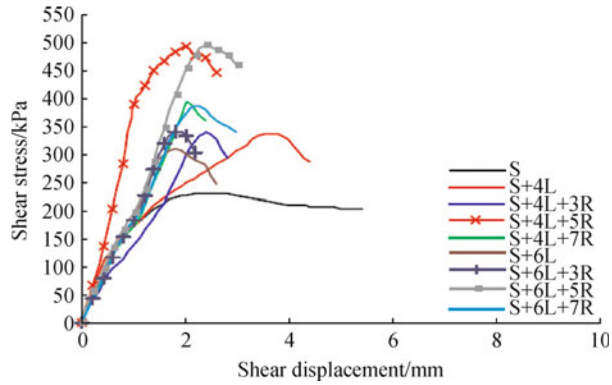

Fig. 14 Stress-strain curves of 28-d samples with normal load equal to 300 kPa

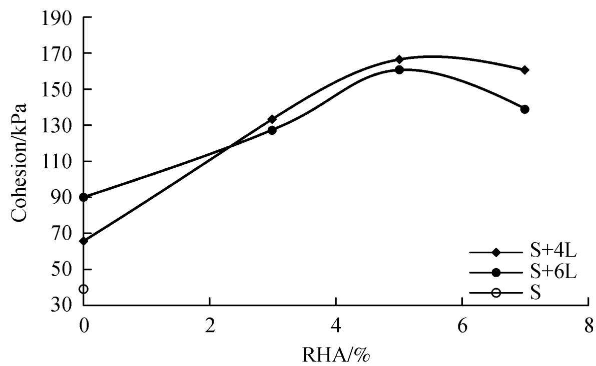

Fig. 15 Influence of lime and RHA on cohesion of 28-d soil samples

As shown in Fig. 15, adding lime to soil causes an increase in cohesion. Moreover, adding RHA to combination of soil and lime (up to 5%) causes an increase in cohesion and then shows a decrease. Based on Fig. 16, adding lime generally causes an increase in internal friction angle. Moreover, adding RHA to combination of soil and lime up to 3% shows a decrease in internal friction angle, and then, adding RHA up to 5% leads to a reduction in the mentioned parameter. Finally, adding RHA, which is more than 5%, shows a reduction in internal friction angle.

Based on that in Figs. 17–19, shear strength of soil increases by adding lime. This increase is larger for 28-d samples. Moreover, shear strength of soil-lime increases with RHA amount increase. These figures clearly show that RHA increase, more that 5%, does not have positive influence on shear strength quantity.

3.5.3 Influence of sample age on shear strength parameters

According to that in Fig. 20, after caring the samples, the highest rate of increase in strength occurs in the first 7 d. This subject is more obvious for the combination of soil, lime, and RHA.

3.6 Influence of RHA and lime on dilation (expansion) of the soil

According to Fig. 21, adding 4% and 6% lime to the 0-d

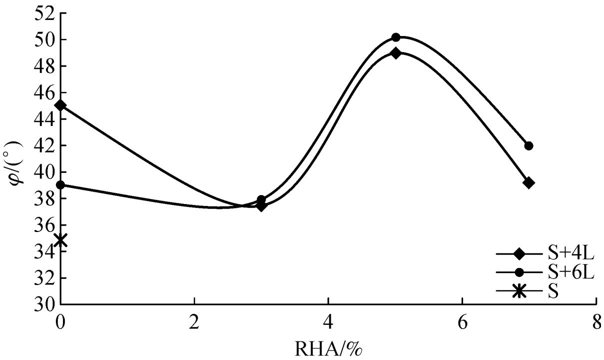

Fig. 16 Influence of lime and RHA on internal friction angle of 28-d soil samples

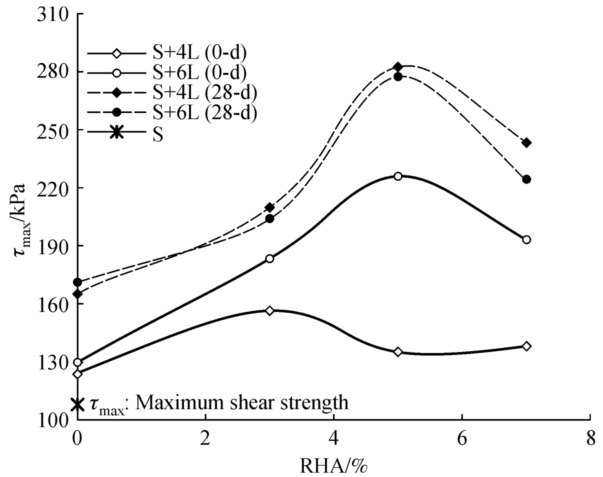

Fig. 17 Influence of lime and RHA on maximum shear strength (normal load = 100 kPa)

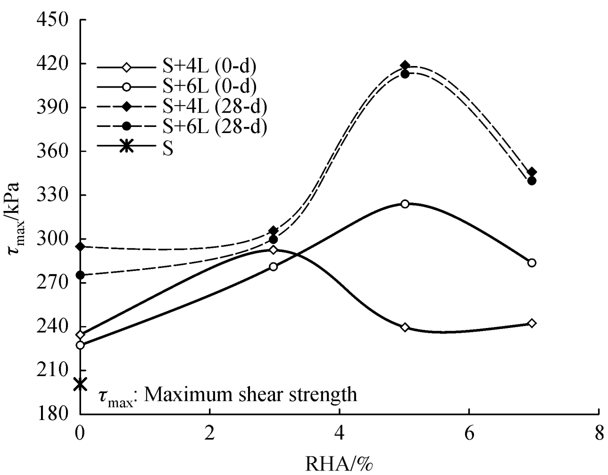

Fig. 18 Influence of lime and RHA on maximum shear strength (normal load = 200 kPa)

soil samples increases the dilation of soil, and for the combination of soil with 4% lime, adding RHA increases dilation parameter, and this increase is the maximum amount for 5% and 7% RHA. For the combination of soil

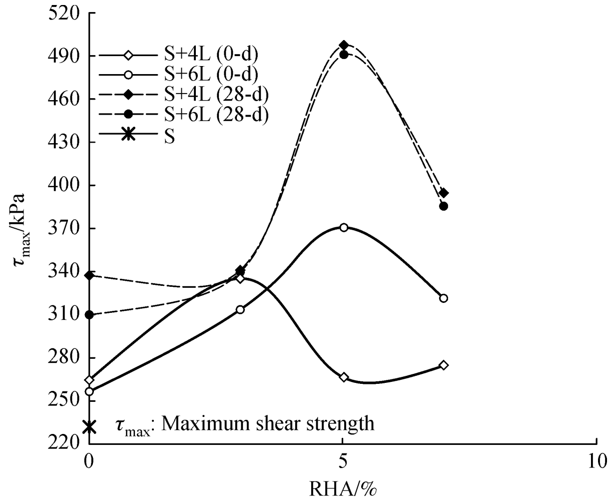

Fig. 19 Influence of lime and RHA on maximum shear strength (normal load = 300 kPa)

with 6% lime, adding RHA causes a decrease in dilation parameter.

Moreover, according to Fig. 22, adding lime to the soil causes an increase in vertical displacement of soil; on the other hand, adding RHA to the soil, more or less, causes a decrease in dilation of vertical displacement of soil. The reason is that RHA makes the shear surface smooth.

3.7 Influence of lime and RHA on CBR test results

As an indicator of compacted soil strength and bearing capacity, this test is widely used in the design of base and subbase material for pavement. It is also one of the common tests used to evaluate the strength of stabilized soils. The influence of lime and RHA on CBR is shown in Figs. 23 and 24, respectively, for the situation of optimum water content and saturation. As shown, adding 4% and 6% lime to the soil for optimum water content (ω_{opt}) results in an increase in CBR parameter about four times. By adding RHA to the combination of soil-4%lime, CBR parameter increases. However, for the combination of soil with 6% lime, CBR curve rises by 5% RHA and then shows a downward trend, adding more than 5%. The gradual decrease in the CBR after adding 5% RHA may be due to excess RHA that was not mobilized in the reaction. Trends shown in Figs. 23 and 24 are in agreement with Alhassan (2008) and Jha and Gill (2006). Using comparison between obtained results concludes that the most suitable and economical combination from CBR point of view is the combination of soil with 4% lime and 5% RHA (S + 4L + 5R).

In the saturation state, soil strength decreases about 34%. In similar condition, the strength of soil with 4% lime decreases about 11.1%, and the strength of soil with 6% lime decreases about 5.7%. For the several combinations of soil, lime and RHA, soil strength decreases about 8.5% on the average.

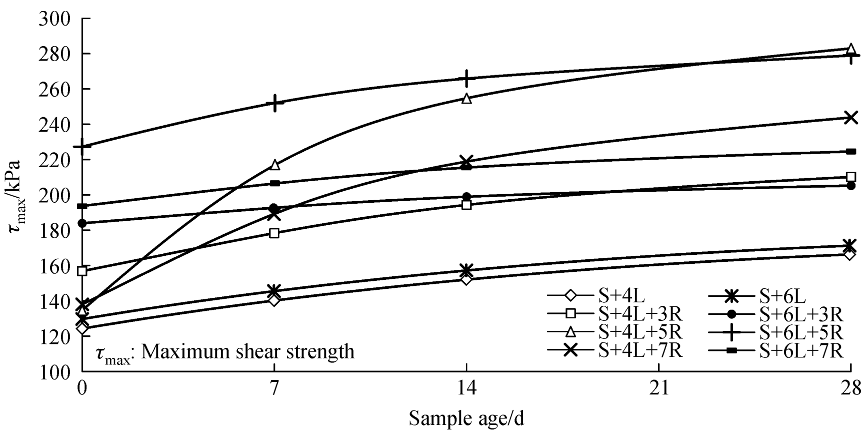

Fig. 20 Influence of sample caring on maximum shear strength (normal load = 100 kPa)

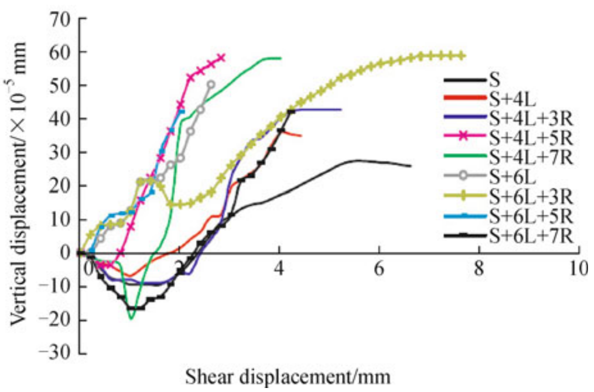

Fig. 21 Influence of lime and RHA on dilation parameter of 0-d samples (normal load = 200 kPa)

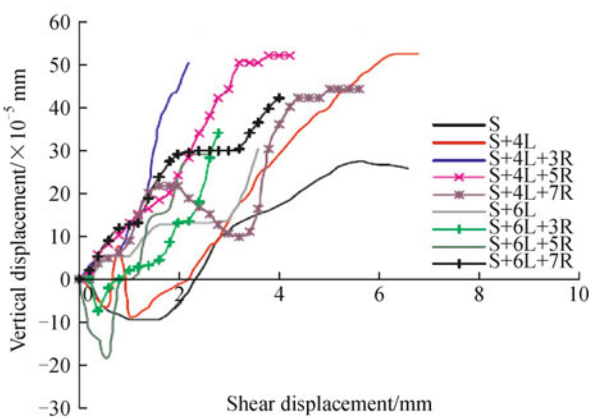

Fig. 22 Influence of lime and RHA on dilation of 28-d soil samples (normal load = 200 kPa)

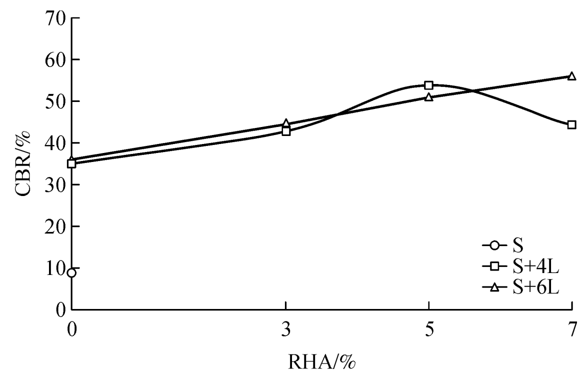

Fig. 23 Influence of lime and RHA on CBR test results of the soil (optimum water content)

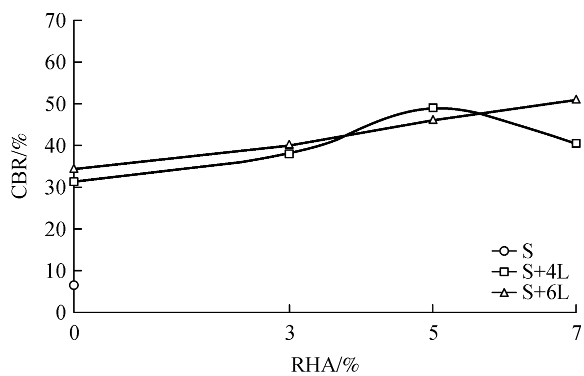

Fig. 24 Influence of lime and RHA on CBR test results of the soil (saturated condition)

4 Conclusions

The influence of adding RHA on amount and quickness of soil and lime reaction using laboratory tests are investigated in this paper, and conclusions are presented as follows:

1) Increasing the amount of lime makes the soil lighter. Moreover, increasing the amount of RHA causes a decreasing rate in dry density. The reason is that the specific gravity of lime and RHA is less than the soil.

2) Increasing the amount of lime and RHA causes an increase in optimum water content. The reason is the activation of pozzolan reaction of soil and lime, which needs more water.

3) Increasing the amount of lime and RHA causes a

decreasing rate in liquid limit and plastic limit. Increasing rate of plastic limit is more than liquid limit and finally causes a decrease in PI parameter. The best combination is soil and lime with 5% RHA from PI point of view.

4) Adding lime and RHA to the soil causes a decrease in deformability of soil samples and gives more brittle materials. Moreover, this action causes an increase in shear strength. Maximum shear strength of soil and lime combination occurs in 5% RHA (for both 0-d and 28-d soil samples).

5) For the combination of soil and 4% lime, the maximum amount of cohesion and internal friction angle parameters occurs in the situation of using 3% and 5% RHA.

6) Increasing the amount of RHA to the combination of soil with 4% lime causes an increase in the dilation parameter, but it shows a decreasing rate in the combination of soil with 6% lime.

Finally, this paper shows that increasing the amount of lime and RHA to the soil makes the soil lighter leads to a decrease in dry density and an increase in water content. Moreover, adding RHA to the combination of soil and lime causes a decreasing rate in PI, and the best combination from PI point of view is S + 4L + 5R. Increase in soil shear strength and CBR parameter under influenced by increasing RHA amount is one of main results of this paper. Also, passing time increases shear strength of the soil samples.

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