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Engineering behavior of expansive soils treated with rice husk ash

Mubashir Aziz [*1], Masood Saleem [2b] and Muhammad Irfan [3]

[1] *College of Engineering, Al Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia*
[2] *Geotechnical Engineer, Keller Grundbau GmbH, Dubai, United Arab Emirates*
[3] *Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan*

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Abstract. The rapid urbanization in Pakistan is creating a shortage of sustainable construction sites with good soil conditions. Attempts have been made to use rice husk ash (RHA) in concrete industry of Pakistan, however, limited literature is available on its potential to improve local soils. This paper presents an experimental study on engineering properties of low and high plastic cohesive soils blended with 0-20% RHA by dry weight of soil. The decrease in plasticity index and shrinkage ratio indicates a reduction in swell potential of RHA treated cohesive soils which is beneficial for problems related to placing pavements and footings on such soils. It is also observed that the increased formation of pozzolanic products within the pore spaces of soil from physicochemical changes transforms RHA treated soils to a compact mass which decreases both total settlement and rate of settlement. A notable increase in friction angle with increase in RHA up to 16% was also observed in direct shear tests. It is concluded that RHA treatment is a cost-effective and sustainable alternate to deal with problematic local cohesive soils in agro-based developing countries like Pakistan.

Keywords: rice husk ash; expansive soil; soil stabilizer; plasticity; compaction; compressibility; swell pressure; shear strength

1. Introduction

Several methods have been developed successfully to use pozzolanic materials such as Portland cement, lime, fly-ash, bitumen and polymers for high strength concrete, soil improvement and other civil engineering works (Givi *et al*. 2010, Harichane *et al*. 2011, Subbarao *et al*. 2011, Sutas *et al*. 2012, Sathawane *et al*. 2013, Senol *et al*. 2006). Over the times, these materials have rapidly increased in price due to the sharp increase in the cost of energy since 1970s (Neville 2011). The over dependence on the utilization of industrially manufactured soil improving additives (cement and lime) have kept the cost of soil stabilization very high. Moreover, effective stabilization of CL/CH soils requires 10-14% cement by volume which may be uneconomical and there are shrinkage concerns as well at cement content greater than 8% (Das 2011).

Rice husk (RH), a major agro-waste obtained from the food crop of paddy was generally

*Corresponding author, Ph.D., Assistant Professor, E-mail: mubaziz@imamu.edu.sa

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considered a worthless waste of rice mills. According to Food & Agriculture Organization database of year 2012, Pakistan is the 11th largest rice producer. It is now well established that rice husk ash (RHA) resulting from burnt rice husk has a great a potential as a pozzolanic material. RH production is 20% by weight of the paddy and RHA produced after burning of RH is 18-20% by weight of the husk. Chemically, RHA consists of 82-87% silica (SiO_2) which makes it an excellent substitute of conventional pozzolanic materials for soil stabilization (Jauberthie *et al*. 2000, Muntohar 2004, Jha and Gill 2006).

Cohesive clayey soils are generally poor materials for foundations and involve pretreatment prior to construction. Considerable research has been done on stabilization of these soils using RHA as a viable alternate of conventional pozzolans (Muntohar 2004, Basha *et al*. 2005, Alhassan and Mustapha 2007, Okafor and Okonkwo 2009, Fattah *et al*. 2011, Rao *et al*. 2011). The application of agro-wastes as a soil stabilizing agent for cost-effective and environmentally safe construction practices is desperately needed in agriculture-based developing countries like Pakistan. A number of attempts have been made to use RHA in concrete and construction industry of Pakistan (Memon *et al*. 2008, Bhatti *et al*. 2011, Nawaz *et al*. 2012). However, no research is available to date on potential of locally produced RHA to improve problematic cohesive soils in Pakistan.

2. Objectives of this study

Most of stabilization has to be undertaken in soft soils (silty, clayey peat or organic soils) in order to achieve desirable engineering properties. According to Sherwood (1993), cohesive soils are easy to stabilize chemically due to their large surface area in relation to their particle diameter. The present paper explores the potential application of RHA as a soil stabilizing agent for local cohesive soils. The rapid urbanization in Pakistan is causing scarcity of sustainable construction sites with good soil conditions. A low-cost alternate is to improve the engineering properties of the encountered soils using agro-waste (RHA) due to the fact that these wastes are mostly dumped in streams/rivers after being utilized as an industrial fuel.

Physico-mechanical properties of low and high plastic cohesive soils treated with RHA were explored through various laboratory tests keeping in view the factors highlighted by (Muntohar 2004, Chandaresekhar *et al*. 2006). Weather resistance, permeability and cyclic behavior of RHA treated soils is recommended for future research.

3. Test materials

3.1 Soil samples

Two different soil samples were collected from Lahore and Dera Ghazi Khan (Pakistan) named as NES and HES, respectively based on their plasticity. The sampling locations are typical alluvial deposits consisting of alternate layers of clays and/or silty clays and sands and/or silty sands of varying thickness and consistencies extending to depths of more than 500 m and below (see Fig. 1).

The physical and chemical properties of soil samples are given in Table 1. Generally, a soil with liquid limit (w_L) > 40%, plasticity index (I_P) > 20%, shrinkage limit (SL) > 6%, and free swell

> 5% is categorized as highly expansive soil. The expansive nature of HES was confirmed by XRD analysis which revealed the presence of Montmorillonite mineral of Smectite group (see Fig. 2).

Fig. 1 Location map of the sampling sites

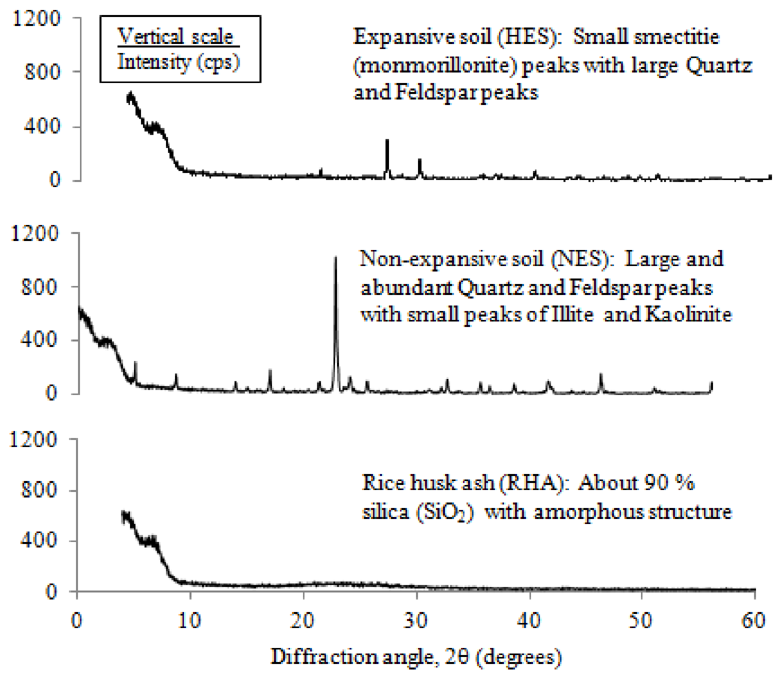

Fig. 2 X-ray diffraction analysis of soil samples and RHA

Table 1 Physical and chemical properties of the soil samples tested as per ASTM

Description	Units	NES	HES
Natural moisture content	%	5.3	16.7
Fine contents	%	79	97
Liquid limit, w_L	%	24	63
Plasticity Index, I_P	%	4	33
Shrinkage Limit, SL	%	-	12
Shrinkage Ratio, SR	-	-	1.9
Specific gravity	-	2.69	2.72
USCS soil classification	-	CL-ML	CH
Maximum dry unit weight	kN/m^3	18.6	18.2
Optimum Moisture Content	%	10.2	13.2
pH Value	-	7.3	6.9
Sulphate content, SO_4	%	0.008	0.024
Chloride content, NaCl	%	0.005	0.020
Organic matter content	%	0.089	0.149

(a) De-husking of paddy (b) RH burning option-1 (c) RH burning option-2

(d) RH burning option-3 (e) Laser temperature gun (f) Burnt RH at room temperature

Fig. 3 Different procedures adopted to burn RH

(a) Grinding machine (b) Milling technique

Fig. 4 Grinding procedures adopted to obtain RHA from burnt RH

Table 2 Effectiveness of various RHA burning and grinding options used in this study

Process	Option	Description	End Product	Figure
Burning	1	Using kerosene oil	Incomplete burning produced large amount of unburnt RHA with high carbon contents	3(b)
	2	By placing container over a flame	Insufficient flame capacity to completely burn RH	3(c)
	3	Burning RH in a furnace at a controlled temperature of 700°C for one hour	More quantity of RHA was produced having the required amorphous structure	3(d)
Grinding	1	Using grinding machine	Less yield of RHA after passing sieve # 100. (A lot of hazardous ash-dust was encountered)	4(a)
	2	Using milling technique	Acceptable yield and quality of RHA after passing sieve # 100	4(b)

3.2 Rice husk ash (*RHA*)

Rice husk was collected from a rice mill in Lahore Pakistan and was burnt using three different techniques: see Figs. 3(a)-(f). Afterward, two different grinding options were employed: see Figs. 4(a)-(b). The discussion on *pros and cons* of each method is given in Table 2. The recommended burning (see Fig. 3(d)) and grinding (see Fig. 4(b)) procedures opted in this study were on the basis of the quality of burning and quantity of RHA passing through 0.15 mm sieve. The chemical composition of RHA used in this study is listed in Table 3.

4. Experimental program

The effects of RHA on soil behaviour by varying its percentage as 0, 4, 8, 12, 16 and 20% (by dry weigh of soil) were investigated through various laboratory tests performed as per relevant ASTM standards i.e., Atterberg limits, modified compaction, one-dimensional consolidation, free swell / swell pressure, and direct shear tests. About one hundred different tests were performed on RHA treated NES and HES soil samples.

5. Results and discussion

5.1 Atterberg limits of RHA treated soil

Liquid limit of NES decreased by 29.2% when 20% RHA (by dry weight of soil) was added to the soil (see Fig. 5). A negligible variation in plastic limit of NES was observed up to 8% RHA. NES became non-plastic (NP) with further addition of RHA. Hence, there is only little benefit of treating low-plastic cohesive soils with RHA. However, a decrease of plasticity index by 39.4% were observed with 20% RHA for HES sample. The general decrease in liquid limit and increase in plastic limit is attributed to the fact that the RHA reaction forms compounds possessing cementitious properties i.e., calcium silicate cement with soil particles. This results in the formation of a compact mass causing an overall decrease in plasticity index of soil.

Shrinkage limit (SL) of HES samples increased from 12 to 22% while shrinkage ratio (SR) decreased from 1.9 to 1.35 with 20% RHA (see Fig. 6). It depicts that volumetric expansion of RHA treated HES would trigger at higher moisture content. Decrease in SR indicates a reduction in swelling potential of RHA treated cohesive soils which is beneficial for problems related to placing pavements and footings on such soils.

Table 3 Chemical analysis of RHA

Constitute	%
SiO_2	89.3
MgO	0.40
Al_2O_3	2.50
Cr_2O_3	0.70
$BaSO_4$	0.014
Fe_2O_3	0.40

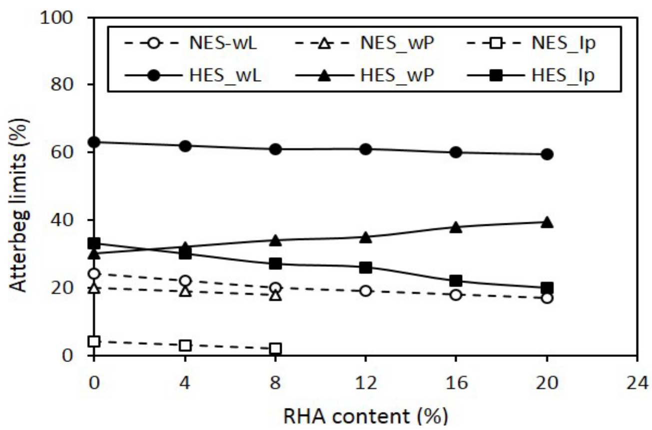

Fig. 5 Effects of RHA on Atterberg limits of soil samples

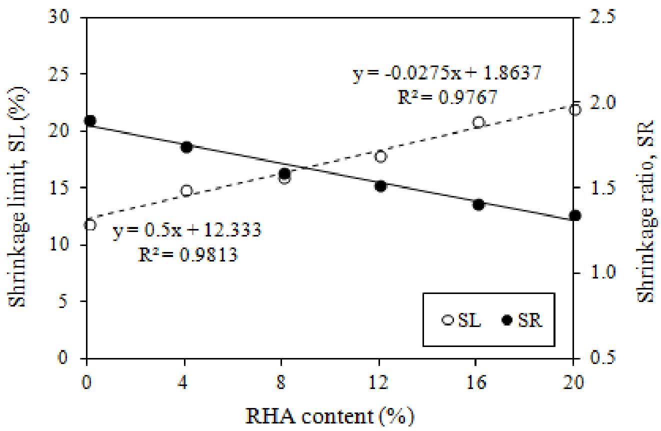

Fig. 6 Effect of RHA on shrinkage behavior of expansive soil (HES)

5.2 Specific gravity of RHA treated cohesive soils

Specific gravity of NES decreased from 2.693 to 2.372 while for HES it decreased from 2.727 to 2.451 with increase in RHA from 0 to 20% (see Fig. 7). The decrease in G_s of RHA treated soils is due to the fact that light-weight RHA particles (G_S = 1.719) replaced the relatively heavier soil particles.

5.3 Effects of RHA on compaction characteristics

The variations of maximum dry unit weight ($\gamma_{d\max}$) and optimum moisture content (OMC) with RHA are given in Fig. 8. With increase in RHA from 0-20%, OMC of NES and HES increased by 130% and 43%, respectively, whereas, $\gamma_{d\max}$ decreased by 25% and 19%, respectively.
The decrease in unit weight is due to the replacement of soil by RHA since the specific gravity of RHA (1.719) is relatively lower as compared to the NES (2.693) and HES (2.727) samples.

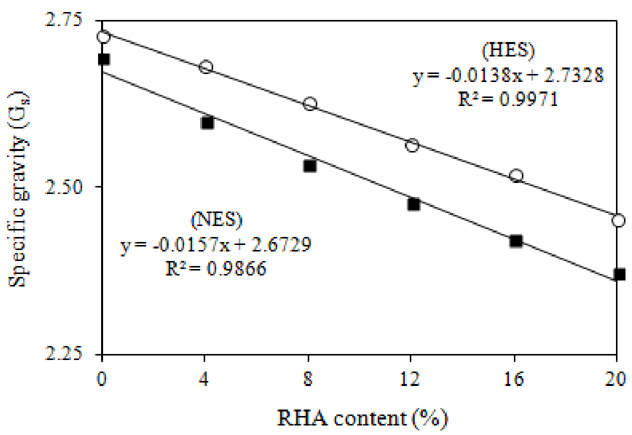

Fig. 7 Effect of RHA on specific gravity of soil samples

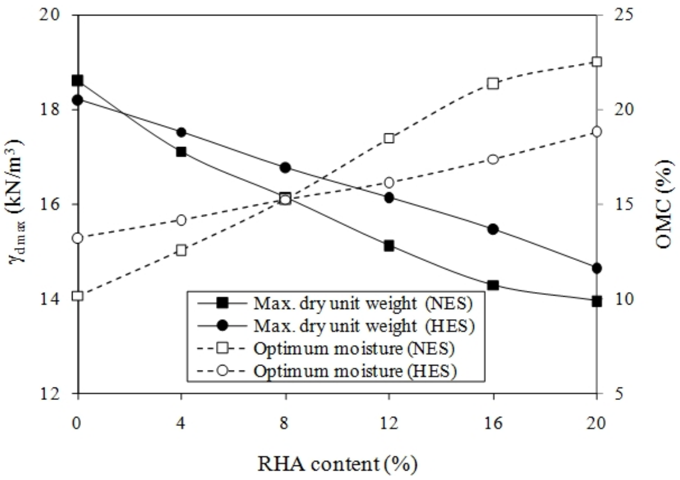

Fig. 8 Variation of optimum moisture content and maximum dry unit weight with RHA

Similarly, RHA being a porous material absorbs more water which causes an increase in optimum moisture by increasing the RHA contents. This implies that to achieve the same density, more water is needed to compact RHA treated cohesive soils (Osinubi 1999) which can be referred to as 'negative benefit' of RHA for compacted fills.

5.4 Compressibility of RHA treated cohesive soils

The oedometer test samples were prepared at 16% moisture content and 14 kN/m^3 density for each concentration of RHA. The decrease in compression index, C_c (calculated between 200-400 kPa) and coefficient of consolidation, C_v (using Taylor's method at a pressure range of 196-392 kPa) are shown in Figs. 9-10, respectively.

The decrease in compression index with RHA is due to the increased formation of pozzolanic products within the pore spaces of soil from physico-chemical changes (Osinubi *et al*. 2009). This also transforms RHA treated soils to a compact mass which decreases both total settlement and rate of settlement. C_c is directly related to the consolidation settlement of soils which implies that RHA can be effectively used to reduce the settlement. Based on the results of HES samples, an optimum RHA of 8-12% is recommended to control C_c and C_v of expansive soils.

5.5 RHA effects on free swell and swell pressure

The computed values of swell pressure and free swell are presented in Fig. 11. With increase in RHA from 0 to 20%, swell pressure decreased by about 80%, whereas, free swell decreased by 63%. Fig. 12 compares the relationship between plasticity index and free swell with the findings of Mallela *et al*. (2004).

The remarkable decrease in swelling potential of HES is attributed to non-cohesive and non-swelling characteristic of RHA. This shows significant potential of using RHA for treating expansive soils. It can further be explored by using the relationships between swelling potential, percentage of clay type, and plasticity index.

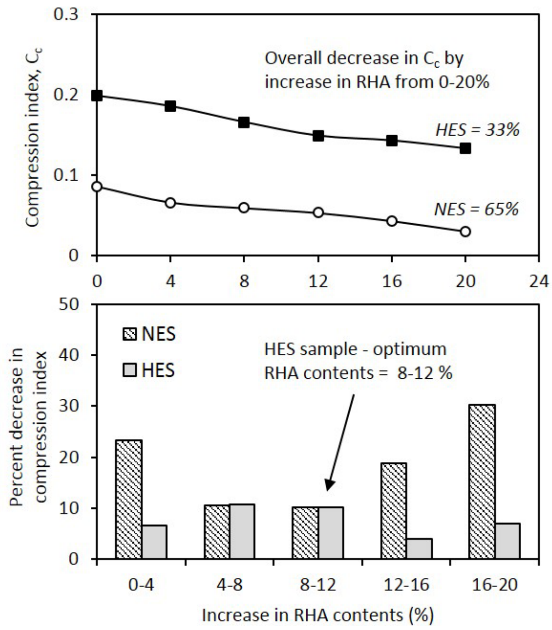

Fig. 9 Compression index of RHA treated soil samples

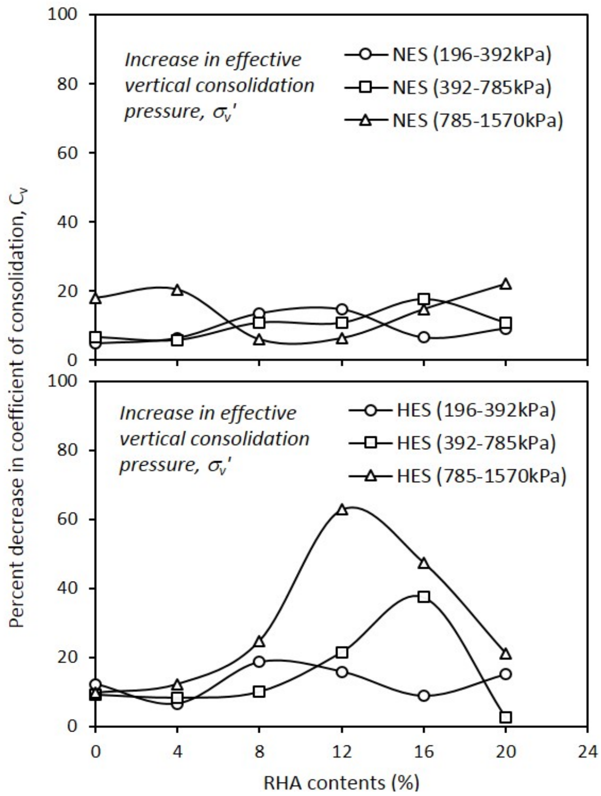

Fig. 10 Coefficient of consolidation of RHA treated soil samples

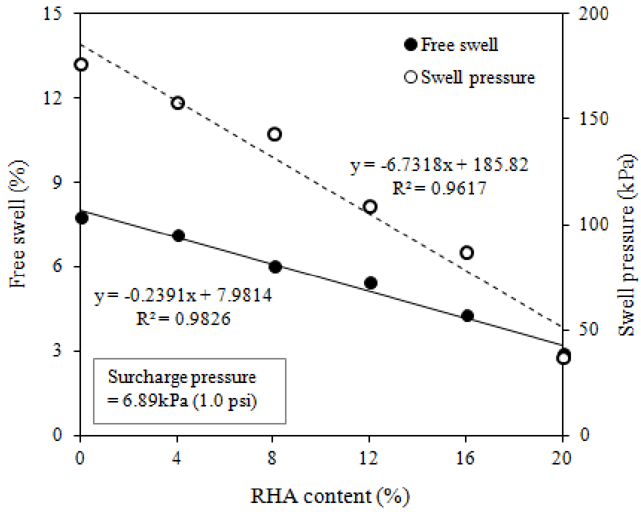

Fig. 11 Influence of RHA on swell pressure and free swell of HES soil sample

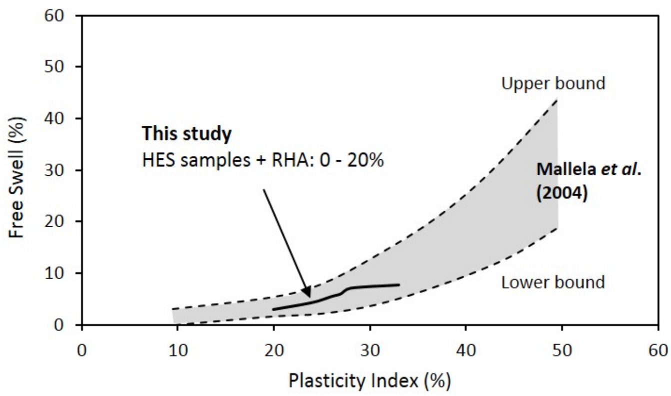

Fig. 12 Relationship of plasticity index with free swell (after Mallela *et al*. 2004)

5.6 Shear strength parameters of RHA treated cohesive soils

It is well known that highly plastic soils have low shear strengths which further decreases upon wetting or other physical disturbances. Therefore, these soils are prone to shear failure due to the constant load over time and considered poor material for foundations (Liu and Evett 2008). The variation of shear strength parameters (c and ϕ of RHA treated samples as determined through direct shear tests at normal stress of 100, 150 and 200 kPa is shown in Fig. 13. It can be observed that with an increase in RHA from 0% to 16%, ϕ increases by 46% and 35% for NES and HES samples, respectively. With further increase in RHA contents, friction angle starts decreasing. The cohesion intercept is not significantly affected with addition of 0-16% RHA to both soil types.

The increase in friction angle with RHA can be attributed to the additional frictional resistance from RHA. However, decrease in c and ϕ occurs with RHA contents greater than 16% possibly due to replacement of soil particles with RHA. Nonetheless, for all practical purposes, the optimum

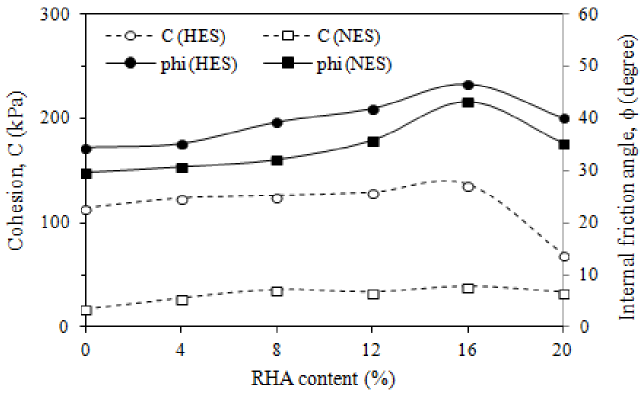

Fig. 13 Variation of shear strength parameters c and ϕ with RHA

Table 4 Comparison of various stabilizers for cohesive soils

Soil properties	This study (CL-ML + RHA: 0-20%)	This study (CH + RHA: 0-20%)	Yadu *et al.* 2011 (RHA: 0-15%)	Yadu *et al.* 2011 (FA: 0-15%)	Malella *et al.* 2004 (CL + lime 0-5%)	Muhunthan and Sariosseiri 2008 (cement: 0-12.5%)	Sarkar *et al.* 2012b (CL + cement: 0-12.5%)	Sarkar *et al.* 2012 a (CL +RHA: 0-12.5%)
% decrease in G_S	11.9	10.1	8.0	6.8	-	-	-	7.9
% decrease in I_P	-	39.4	64.7	17.6	-	45.6	15.8	16.7
% increase in SL	-	83.3	-	-	-	-	-	54.5
% decrease in SR	-	29.0	-	-	-	-	-	15.4
% decrease in $\gamma_{d\max}$	25	19.5	14.0	31.7	6.2	6.1	4.0	8.4
% increase in OMC	131.5	42.4	63.9	2.5	18.9	5.6	22.7	41.9
% decrease in free swell	-	62.7	-	-	-	-	-	50
% decrease in swell pressure	-	79.1	-	-	60.7	-	-	-
% decrease in C_c	65	33.2	-	-	-	73.8	50	29.9
% increase in ϕ'	30	23.5	-	-	-	-	175 (28-days soaking)	-

RHA content offering the maximum shear strength should be evaluated, although the swell potential keeps on decreasing with RHA.

6. Comparison of RHA with other stabilizers

Table 4 presents the comparison between findings of this study and previous research work on improving various engineering characteristics of cohesive soils using various stabilizers such as; rice husk ash (RHA), fly ash (FA), lime and cement.

It can be observed in Table 4 that the effects of all stabilizers on various soil properties have similar trends, in general. However, the definition of modification and stabilization can be ambiguous because the modification refers to soil improvement that occurs during or shortly after mixing and stabilization occurs when a significant, longer-term pozzolanic reactivity or hydration reaction takes place. Nevertheless, the ability to decrease the plasticity, compressibility, and swelling potential and increase in the shear strength are reasonable criteria to select a modifier / stabilizer for problematic local soils keeping in view the cost and availability.

7. Conclusions

The aim of this study was to explore rice husk ash production at small-scale from abundantly available rice husk in Pakistan and to introduce RHA to improvement local problematic soils. The test results showed encouraging signs for improving various geotechnical properties of such soils. The main conclusions derived from this research work are:

- The decrease in plasticity due to agglomeration of soil grains with non-plastic RHA particles modifies the soil type from high to low plastic.
- The increase in shrinkage limit and the decrease in shrinkage ratio depicts that the volume reduction will cease at higher moisture content which is beneficial for geotechnical concerns related to placing pavements and footings on such problematic soils.
- RHA significantly affects the compaction characteristics of cohesive soils as more moisture will be needed for RHA treated cohesive soils to compact into a denser state.
- The decrease in compressibility indices decreases both total settlement and rate of settlement. A significant reduction in swell potential of expansive soil is also observed.
- RHA content of 16% gave peak values of shear strength parameters which decrease afterwards due to partial replacement of soil contents with RHA. However, further investigation is needed to explore the possible effects of soil type on optimum RHA content.
- The commercial production cost of RHA in Pakistan is about 65 US$ compared with 90 and 100 US$ per ton for cement and lime, respectively (according to the rate analysis in year 2012). In agriculture-based developing countries like Pakistan, utilizing RHA to improve expansive soils can be relatively more environment-friendly and cost-effective as compared to cement and lime. Large scale burning of RH can be carried out at construction sites and the grinding can be achieved by passing rollers over RHA.

Further research is intended through CD and CU triaxial tests under monotonic and cyclic loadings in order to extend our knowledge on effects of RHA on permeability, creep, pore-water pressure, and cyclic behavior.

Acknowledgments

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