Evaluation of the strength characteristics of clayey soils stabilized with rice husk ash and cement

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Abstract

Portland cement is widely used as a chemical admixture in ground improvement projects. However, cement production is facing tremendous challenges such as depleting natural resources, increasing costs of energy supplies, and environmental concerns due to CO_2 emission. Utilization of waste materials and industrial by-products in soil stabilization is a possible method of reducing the required cement quantity. Rice husk ash (RHA) is a highly reactive pozzolan generated from the burning of rice husk as an agriculture by-product of rice milling. This paper demonstrates the effect of using rice husk ash and cement on strength characteristics of clayey soils. In this regard, unconfined compressive strength and California bearing ratio tests were performed on combinations of the constituent materials. The results of study revealed significant improvement in soil strength after stabilization with cement and RHA. Addition of 10% rice husk ash is recommended as an optimum amount in soil stabilized with 3% cement.

Keywords: Soil Stabilization, Rice Husk Ash, Cement, Strength

1. INTRODUCTION

One of the most common geotechnical problems in civil engineering is the failure of structures or pavements due to low bearing capacity and high compressibility of the underlying soils. Stabilization of these soils can be accomplished by mechanical or chemical stabilization methods, by which the engineering properties of the soil are improved. In chemical soil stabilization, the reaction between the soil and the additives can be divided in two different groups: (1) immediate reaction take place in which cation exchange and the associated phenomenon of flocculation and agglomeration of the soil particles occur; (2) pozzolanic reaction take place in which clay particles react with binder to form cementitious compounds in long periods of time [1, 2].

Portland cement is a comprehensive chemical stabilizer widely used in ground improvement projects. However, cement stabilization is nowadays not desirable because of environmental issues associated with the CO_2 emissions from the production of Portland cement, energy demand, resource conservation consideration, and economic impact due to the high cost of Portland cement production. Accordingly, in recent years, a great effort has been done to develop alternative agents or non-conventional additives, especially those that are more effective and less costly, for a sustainable soil stabilization process [2-6].

Rice husk (RH) is an agricultural waste produced as by-product of rice milling after breakdown of the rice from paddy. Nowadays, more than 120 million tons of rice husk are produced in the world annually [7]. In Iran, where rice production has had a dramatic increase over the past ten years, more than 2.6 million tons of rice paddy are annually produced [8]. Because RH accounts for approximately 20% by weight of the paddy [7], more than 0.5 million tons of RH is annually generated in Iran. The energy density of RH is reported to be approximately 16720 kJ/kg [9] and, therefore, it can be used as a fuel source in boilers for energy production. However, the use of this fuel generates new waste with no useful application, designated as rice husk ash (RHA). The chemical composition of RHA depends on temperature and burning time, but the variations in the components are not significant [7]. Research has shown that burning rice husks at temperature below 700 °C can result in the formation of rice husk ashes with high pozzolanic activity because amorphous silica is formed in RHA [7, 10].

Because rice husk ash is not self-cementitious, it cannot be used alone for soil stabilization. However, the high quantity of silica in RHA and its high specific surface because indicate that it has potential pozzolanic properties and can be used in soil stabilization applications with the addition of a cementitious agent such as lime or Portland cement [6, 11].

The primary objective of this study is to investigate the effect of RHA as a waste material on strength properties and microstructural characteristics of cement treated clayey soil. Accordingly, unconfined compressive strength and California bearing ratio (CBR) tests were conducted on stabilized samples with cement and different percentage of RHA. Also, scanning electron microscopy (SEM) test was carried out to identify the underlying mechanisms and microstructural modification.

2. MATERIALS AND METHODS

The soil used in this study was 70:30 mix of commercial kaolinite and bentonite. The particle size distributions of the soil according to ASTM D422 [12] are shown in Figure 1. Table 1 presents a summary of the geotechnical properties of the soil measured according to ASTM methods. This soil was classified as clay with high plasticity (CH).

An ordinary Portland cement (OPC Type II) produced by the Shahroud cement factory in Iran, was used in this study. The rice husks were collected from a northern state of Iran. The dried rice husk was burned at a temperature of 700 °C with retention time of 30 min. Rice husk ash was passed through sieve No. 200 (75 μm) to remove impurities. The chemical compositions of the stabilizers and soils were determined using the XRF analysis, as indicated in Table 2.

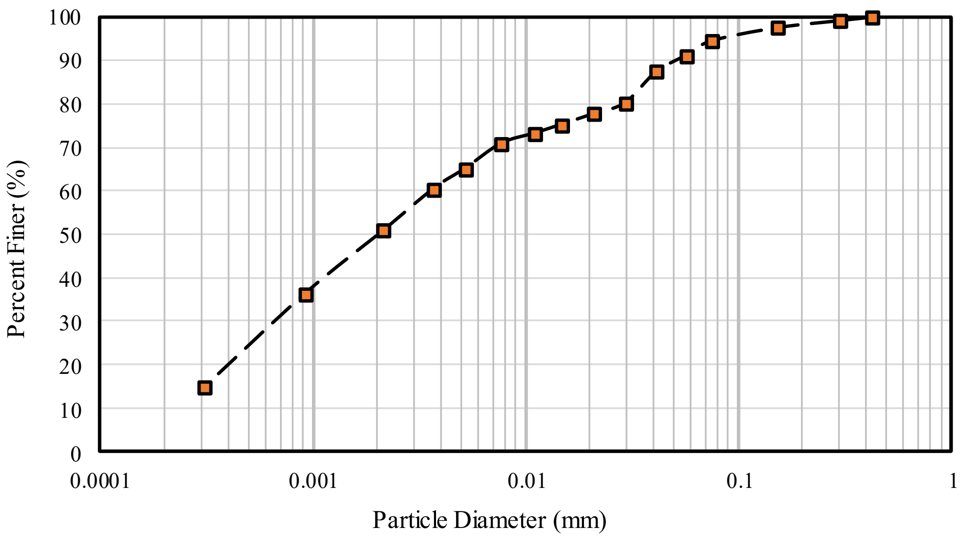


Figure 1. Particle size distribution of soil

Table 1. Properties of soil

Parameters	Value
Liquid Limit, %	89.5
Plastic Limit, %	26
Plasticity Index, %	63.5
Soil Classification	CH
Specific Gravity (G_s)	2.7
Maximum Dry Density, kN/m^3	15.9
Optimum Moisture Content, %	19.1
Unconfined Compressive Strength, kPa	97.2

Table 2. Chemical composition of kaolinite, bentonite, Portland cement and rice husk ash

Compound	Kaolinite	Bentonite	Portland cement	Rice husk ash
SiO_2	72.5	65.53	21.11	93.6
Al_2O_3	18.07	10.44	4.42	0.23
Fe_2O_3	0.36	1.24	3.96	0.2
CaO	1.15	3.23	63.36	1.35
MgO	0.61	1.57	1.51	0.34
SO_3	0.06	1.95	2.61	-
K_2O	0.39	1.31	0.51	2.16
$Na_2O + TiO_2$ + other	0.86	4.98	0.5	0.12
Loss on ignition (% by mass)	6.0	9.75	2.02	2.0

Following the procedures in ASTM D2166 [13], the unconfined compressive strength (UCS) test was conducted on the mixtures of soil, Portland cement and rice husk ash. The percentage of cement (C) used in the mixtures was 3%, while the percentages of RHA were 5%, 10% and 15% by dry weight of the soil. The mixture was first wetted to the desired water content and then grounded by hand to form a homogeneous blend. The specimens were compacted in layers into a split mold of size 38-mm diameter and 76-mm height to achieve dry unit weight corresponding to maximum dry density. The compacted specimens were cured in plastic for period of 7 days at a temperature of 23±2°C. After curing, the sealed specimens were unwrapped from plastic bags and were subjected to UCS test. The mix designs in this study are summarized in Table 3.

Soaked California bearing ratio (CBR) test was measured following ASTM D1883 [14]. The mixtures were kept in sealed plastic bags for 24 h and then were compacted at optimum moisture content. The specimens were cured in a plastic bag to prevent moisture change. After 7 days of curing, CBR test was performed on specimens.

Scanning electron microscopy (SEM) test was conducted on the samples in order to observe the microstructure of the soil in different conditions. Three samples (S, S-3C and S-3C-10RHA) were investigated by using SEM analysis.

Table 3. Mixture proportion

Sample	Portland cement (%)	Rice husk ash (%)
S	0	0
S-3C	3	0
S-3C-5RHA	3	5
S-3C-10RHA	3	10
S-3C-15RHA	3	15

3. RESULTS AND DISCUSSION

Figure 2 shows the effect of various RHA percentages on the stress-strain curves of the cemented soil, which was obtained from the unconfined compressive strength test at curing ages of 7 days. It can be seen that Portland cement led to an increase in the strength of the soil which is reported widely in previous works [1, 2]. Strength development can be attributed to the cementitious links between the calcium silicate and aluminate hydration products and the soil particles. This induces better cohesion and rigidity of clay particles. As can be seen from Figure 3, some pores between the soil particles were filled with cementitious gel, which resulted in a denser soil matrix.

Upon addition of RHA, unconfined compressive strength of the soil–cement composite increases from 2.31 to 6.92 times its strength without stabilizer for RHA contents up to 10% whereas it decreases for higher RHA content (Figure 2). The resulting improvement in UCS value with the addition of RHA can be attributed to the pozzolanic reaction between the clay soil and pozzolanic material forming additional cementitious material that bounds particles together and enhances the strength of the soil. The SEM images in Figure 3 reveal the changes in structure of the cemented soil by the addition of 10% RHA. The changes observed in the mixtures modified with RHA may be the result of a chemical reaction between SiO_2 in RHA and $Ca(OH)_2$ during cement hydration and production of additional Calcium-Silicate-Hydrate (C-S-H) gel in the soil.

The decrease in the strength after addition of 10% RHA may be due to formation of weak bonds (unreacted amorphous silica in RHA) between the soil and the cementitious compounds formed [15]. On the other hand, because RHA is a porous material, some of the water that was added to the mixture was absorbed by the RHA and hence there was not enough water to cause a hydration reaction with the all the cement [16].

Figures 4 demonstrates the stress-penetration curves of specimens in CBR test for the soaked condition. According to the CBR values, it can be concluded that the results of the soaked CBR test are in line with those of the unconfined compressive strength test. Strength development in the specimen with 10% RHA indicates the preliminary possibility of using RHA for replacing cement or adding up in cement for soil stabilization projects.

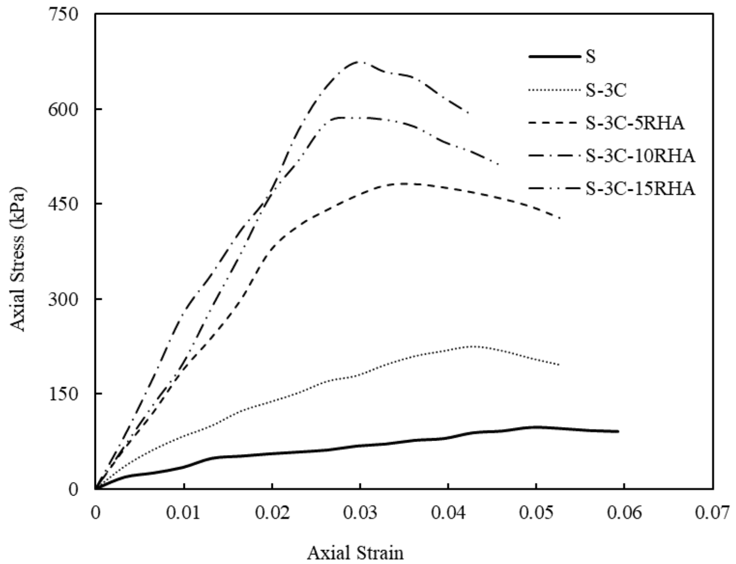


Figure 2. Effect of additives on unconfined compressive strength (UCS)

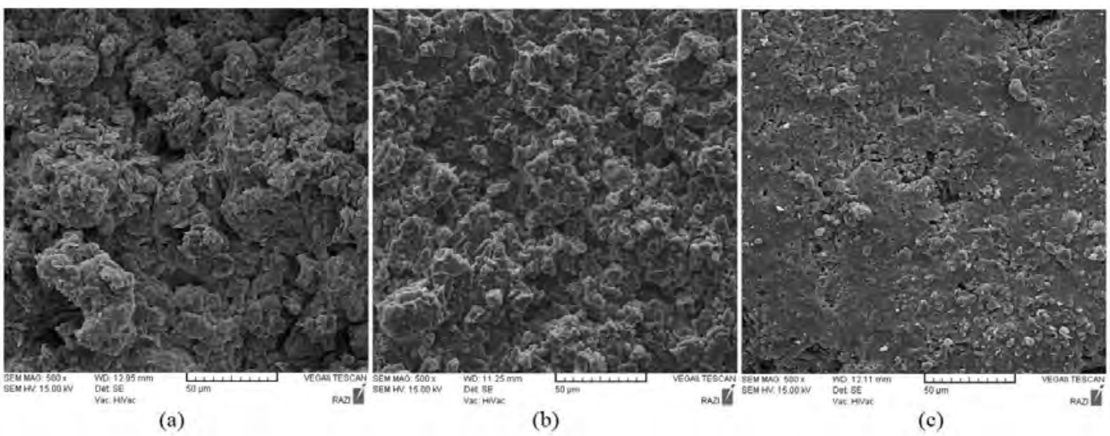
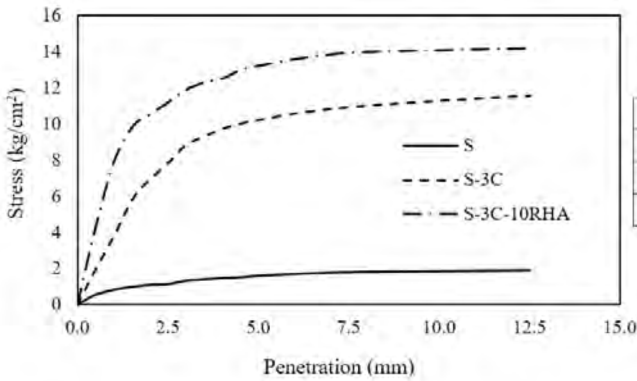


Figure 3. Scanning electron micrographs of specimens: (a) S, (b) S-3C, (c) S-3C-10RHA



Specimens	Soaked CBR value (%)
S	1.6
S+3C	11.3
S+3C+10RHA	16.1

Figure 4. Stress versus penetration plot for specimens in CBR test

4. CONCLUSIONS

Cement stabilization is nowadays not desirable because of environmental issues associated with the CO_2 emissions from the production of Portland cement, energy demand, resource conservation consideration, and economic impact due to the high cost of Portland cement production. Improving soil properties using waste materials and industrial by-products can be applied to solve geotechnical problems and reduce the required cement quantity. This study has been performed to investigate the effect of rice husk ash (RHA) as a waste material on strength properties and microstructural characteristics of cement treated clayey soil. The unconfined compressive strength of cemented soil increases with RHA content with the maximum strength achieved at 10% content (by dry weight of soil) but less increase in strength occurs at higher RHA content. The resulting improvement in strength value with the addition of RHA can be attributed to chemical reaction between SiO_2 in RHA and $Ca(OH)_2$ during cement hydration and production of additional Calcium-Silicate-Hydrate gel in the soil. This induces better cohesion and rigidity of clay particles. According to the CBR values, it can be concluded that the results of the soaked CBR test are in line with those of the unconfined compressive strength test. This research indicated the preliminary possibility of using RHA for replacing cement or adding up in cement for soil stabilization projects.

5. REFERENCES

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