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INVESTIGATING THE EFFECTIVENESS OF RICE HUSK ASH AS STABILIZING AGENT OF EXPANSIVE SOIL

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ABSTRACT: Expansive soils pose a significant threat to structures due to its ability to cause damage from the footing up to the superstructure. This paper intends to provide an economic and environment-friendly method of mitigating the swelling potential of expansive soil by replacing a set volume of expansive soil with rice husk ash (RHA) – an abundant waste material produced by the biomass power plant. The swelling behavior of the soil mixtures was analyzed through its expansion index obtained via ASTM D4829. Results of the tests revealed that the mixture containing 20% and 25% RHA are considered non-expansive soil. Soil stability parameters were also obtained through the tests specified by ASTM D4609. The tests on the soil stability parameters revealed that soil-RHA mixtures exhibited an improvement in the Atterberg limits which garnered a 36.32% decrease in the liquid limit and 64.75% decrease in the plasticity index; however, a decline was observed in the compaction characteristics and the unconfined compressive strength. Soil-RHA mixtures experienced a maximum decrease of 230 kg/m^3 in the maximum dry density and a 40.17% increase in the optimum moisture content. The unconfined compressive strength of treated soils yielded a decrease of as much as 194.2 kPa as well as a decrease in the cohesion development of the soil. The results revealed that while an increase of the RHA content reduces the swelling potential of soil, other strength parameters such as the compaction behavior and the unconfined compressive strength of the soil declines.

Keywords: Expansive soils, Rice husk ash, Soil stability, Expansion index

1. INTRODUCTION

Expansive soils are abundant in tropical countries and locations where volcanic activity is rampant. These soils have often considered as problematic due to the volume change it exhibits when exposed to moisture [1]. Tropical climate conditions can trigger the shrinking during extremely hot weather and swelling during heavy rainfall of expansive soil. On the other hand, volcanic activity produces volcanic soils which eventually weather to clay. These clays are rich in kaolinite and montmorillonite, minerals which increases the shrink-swell potential of soils [2]. The shrink-swell behavior of expansive soils caused differential movement of structures in direct contact to it and therefore increases the probability of structural damage. Considering the potential damage expansive soil may induce to structures, the National Structural Code of the Philippines (NSCP, 2010) provided solutions when expansive soils are identified in the location of construction. One solution suggested by the NSCP is the replacement of expansive soil with a non-expansive fill [3]. However, this may cause several environmental and economic concerns specifically with regards to its transportation and disposal. In order to prevent this possible scenario, an alternative solution is through soil stabilization - a type of soil treatment wherein the soil's engineering properties are improved. One form of such is through chemical stabilization which is performed by adding a certain effective material with the pozzolanic property. Waste materials like bagasse ash and hydrated lime have been found to improve the strength and bearing capacity of stabilized expansive soil while reducing its linear shrinkage [4].

Rice husk is considered the most common agricultural waste in the Philippines. Its properties have been denoted to be highly beneficial specifically when it is incinerated at high temperature and turned into ash. Several studies have recognized rice husk ash (RHA) as an effective pozzolan [5], [6]. The high silica and aluminum content of rice husk ash suggests that it can act as a good chemical pozzolan [7] similar to bagasse ash and hydrated lime. Besides its favorable chemical composition, RHA is relatively cheaper and more abundant compared to other chemicals used for engineering purposes. In most cases, RHA has been widely used for concrete production as cement additives, mine reclamation, and soil stabilization.

This study intends to investigate the effectiveness of rice husk ash (RHA) in mitigating the swelling potential and improving the strength properties of expansive soils. To evaluate its effectiveness, an improvement in the soil's engineering properties, namely Atterberg Limits, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Unconfined Compressive Strength (UCS), and Expansion Index (EI), must be observed. In addition, the study also intends to determine the physical and chemical composition of expansive soil and RHA, and relate its analysis on the development of the index properties of soil-RHA mixtures. The study seeks to determine the best proportion of RHA as a stabilizing agent of expansive soil that will yield the best result in controlling the swelling potential and improving the unconfined compressive strength.

The utilization of RHA as a soil stabilizing agent is heavily recommended, considering that about 2 million tons of rice husks are annually produced in the country [8]. This study provides an environmentally-friendly, economical and effective approach to mitigating the swelling potential of expansive soils; therefore, eliminating the numerous hazards it imposes. The study also intends to provide an alternative solution in disposing of the rice husk ash produced by biomass power plants.

2. MATERIALS AND METHODS

2.1 Source of Expansive Soil

The soil used for the study was identified by using the soil map provided by the National Mapping and Resource Information Authority (NAMRIA). From this soil map, it was revealed that soils located around Pulang Lupa, Las Piñas City, Metro Manila contained Guadalupe Clay, a type of clay which is known to exhibit a high shrink-swell behavior [9]. The samples were specifically collected from an on-going construction site at a depth of more than 5 meters to ensure that no organic materials were present. The collected soil exhibited a dark shade of gray when moist, which is an indicator of a clayey soil (Fig. 1a). The moist soil samples also exhibited a sticky texture when touched, which signifies that it is cohesive when exposed to moisture. When dry, the soil samples exhibited a significant amount of cracking and its volume significantly decreased - an indication of high shrinking and swelling potential (Fig. 1b).

2.2 Source of Rice Husk Ash

The rice husk ash (RHA) used in this study (Fig. 2) was obtained from Restored Energy Development Corporation - a local Biomass Power Plant located in Muntinlupa City, Metro Manila. Initially, rice husks were delivered from rice plantations in Central Luzon and incinerated in the plant at a constant high temperature to produce Biomass energy. Through this process, RHA is generated as a byproduct. The RHA was sourced from only one power plant to ensure that the properties of the material are consistent. To avoid the deterioration of quality, the material was fully contained and placed away from moisture and harsh environments.

a.) moist soil b.) dry soil

Fig. 1 Soil sample in this study

Fig. 2 Rice husk ash (RHA) used in the study

2.3 Experimental Program

Prior to testing the effects of rice husk ash on various soil properties, the extracted soil samples must be classified as expansive. This was done in accordance with the provisions set by Section 303.5 of the NSCP 2010 [3]. Table 1 presents the required parameters to classify the soil as expansive. These parameters were obtained through conducted laboratory experiments in accordance with their respective ASTM standards.

Based on Unified Soil Classification System (USCS) criteria, soils which are classified as CL (Lean Clay) with liquid limit (LL) less than 50 and plasticity index (PI) greater than 7 and soil classified as CH with LL greater than 50 or more and PI plots on or above the “A” line of the plasticity chart are usually considered as potentially expansive.

Table 1 Expansive soil classification summary

Required Parameters	NSCP Criteria
Liquid Limit, LL (%) Plasticity Index, PI (%)	Plasticity Index (PI) of 15 or greater and Liquid Limit greater than 50.
Percentage of soil particles passing the #200 (0.075 mm) sieve opening (%)	More than 10% of the soil particles pass the #200 sieve.
Percentage of soil particles less than 5μm in size (%)	More than 10% of the soil particles are less than 5μm in size.
Expansion Index, EI	An expansion index value greater than 20.

Table 2 summarizes the laboratory tests done to determine the potential for shrink-swell behavior. In addition to these laboratory tests, soil and RHA were subjected to Scanning Electron Microscopy test (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) to determine its micro fabric structure and chemical composition.

Table 2 Laboratory tests to determine the index properties and expansive behavior of soil sample preparation

Experimental Program	Test Standard
Specific Gravity Test	ASTM D854
Grain Size Analysis (Mechanical and Hydrometer Method)	ASTM D422
Liquid Limit Test	ASTM D4318
Plastic Limit Test	ASTM D4318
Shrinkage Limit Test	ASTM D427
Minimum Index Density Test	ASTM D4253
Maximum Index Density Test	ASTM D4254
Expansion Index Test	ASTM D4829

2.4 Standard Tests for the Evaluation of RHA as an Admixture

To evaluate the effectiveness of RHA as an admixture, the soil mixtures must be tested as prescribed by ASTM D4609 – Standard Guide for Evaluating Effectiveness of Admixtures for Soil Stabilization, and the criteria that must be met are summarized in Table 3. Three experimental tests were performed for each soil-RHA mixture. In addition to the ASTM D4609 criteria, the soil's expansion index (EI) must also be known following the procedure of ASTM D4829. The RHA will only be deemed as effective if the resulting EI value of the soil mixture is below 20.

Table 3 Criteria to gauge the effectiveness of RHA as an admixture

Parameter	ASTM D4609 Criteria
Liquid Limit, LL (%) Plasticity Index, PI (%)	A significant reduction in the LL and PI
Maximum Dry Density (MDD), (kN/m^3) Optimum Moisture Content (OMC), (%)	A decrease of greater than 15% in OMC or an increase of more than 80 kg/m^3 in MDD.
Unconfined Compressive Strength (UCS), q_u(kPa)	An increase in the UCS of 345 kPa.

2.5 Soil – RHA Mixture Preparation

After classifying the soil as expansive, the samples were blended with RHA through dry mixing. Soil mixtures were formed by replacing a percentage of the soil's volume with rice husk ash, which was formulated using the soil and RHA's index properties. The admixture was added at varying amounts ranging from 5% to 25% at 5% intervals. The mixture was allowed to cure for at least 16 hrs. before subjecting to a series of tests.

3. TEST RESULTS

3.1 Soil Classification

Table 4 presents the summary of the obtained results for the soil's classification.

Table 4 Summary of results on soil classification

Parameter	Required Value	Result	Remarks
Percent Passing #200 Sieve (%)	>10%	55.38	Pass
Percent greater than 5μm (%)	>10%	3.15	Fail
Liquid Limit, LL (%)	>50	74.97	Pass
Plasticity Index, PI (%)	>15	52.31	Pass
Expansion Index, EI	>20	111	Pass
USCS Classifications	CH (Fat Clay)		
Specific Gravity, G_s	2.665		

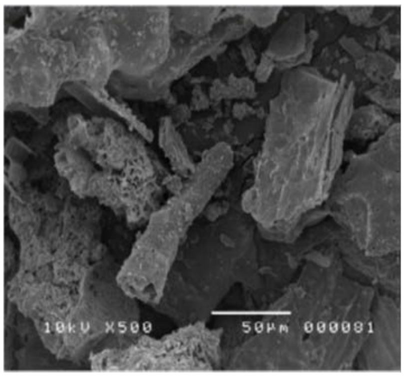
It can be observed that the criterion for the percentage of particles greater than 5μm (ASTM D422) was not satisfied. However, the NSCP section states that a resulting EI value greater than 20 still governs; thus, classifying the soil as expansive. Based on USCS criteria, the soil was classified as Fat Clay with group symbol CH. This is an indication that the soil contains a high amount of clay.

3.2 Micro fabric Structure and Chemical Composition

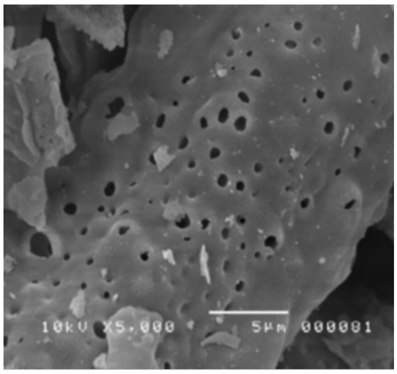
Based on the SEM results of the RHA (Figure 3a), it can be observed that the particles exhibit a randomly arranged aggregation with large spaces. The presence of a cellular-like structure with the significantly high amount of transgranular and intragranular voids was also observed. This is due to the spaces which cut and separate each particle from each other. At greater magnification (Figure 3b), the results exhibited the presence of extra layers with exceedingly small intragranular voids from within its structure. These extra layers and micropores contributed to the significantly high specific area of RHA. In particular, this property plays an important role in proving the high water absorption capability of RHA. The area allows water to adhere; thus, increasing its water adsorption capability.

The SEM result for the clay soil was also observed as presented in Figure 4. The clay particles passing the #200 sieve were considered. The results show that the sample exhibited a highly dense flaky granular arrangement which contains connectors in between the grains, typical to clay particles. Flaky surfaced clays contribute to the adsorption of water due to the capability of its high surface value to carry small negative charges which attract water molecules [10].

The EDX results of both the RHA and soil are presented in Fig. 5. Test results revealed that RHA contains a significantly high amount of oxygen and silicon amounting to about 98% of the material and a small amount of Potassium of about 2%. Several studies revealed that the presence of silica improves the strengthening capabilities of cement or other cementitious material; thus, making the material such as RHA as an effective pozzolan [11]. The chemical composition of soil contains a significantly high amount of iron. The high value of iron is an indication that the soil contains montmorillonite - a mineral which increases the shrink-swell potential of soil [2]. In particular, montmorillonite minerals are mainly composed of iron, aluminum, and silicon - elements similarly present in the EDX results of the clay. In addition, the low amount of carbon indicates that the soil is inorganic.

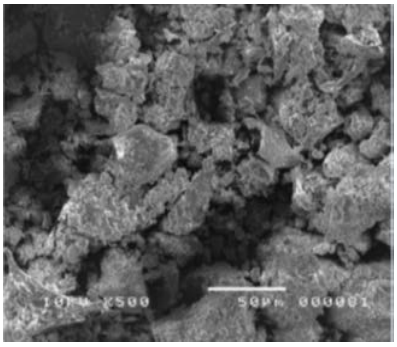


(a) 500x magnification

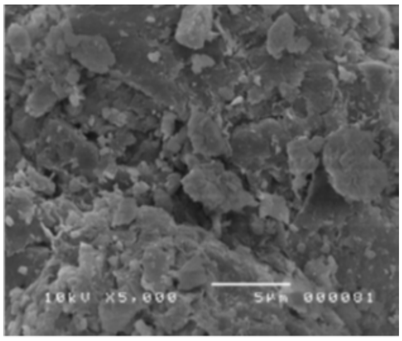


(b) 5000x magnification

Fig. 3 Micrographs of RHA

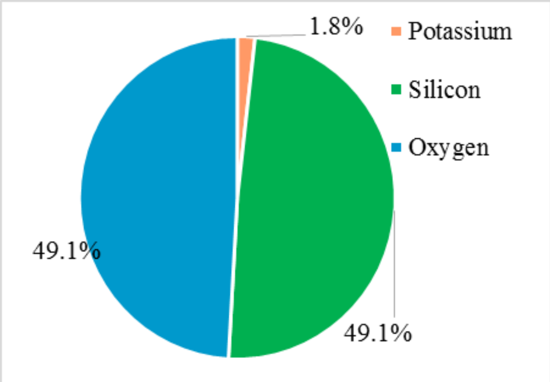


(a) 500x magnification

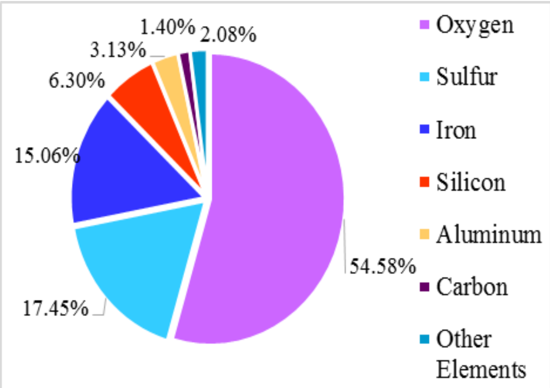


(b) 5000x magnification

Fig. 4 Micrographs of soil sample



(a) RHA



(b) soil

Fig. 5. The chemical composition of a.) RHA and b.) soil

3.3 Evaluation of RHA as Stabilizing Agent

3.3.1 Atterberg Limits

The Atterberg Limits are important parameters which determine the amount of water needed to transform the soil's consistency from one state to another. Table 5 presents the mean values for the Atterberg limits of the soil-RHA mixtures. The standard guide for the evaluation of the effectiveness of soil additive (ASTM D4609) states that a decrease in the liquid limit and plasticity index proves that the additive is effective in improving the Atterberg Limits of the soil. Based on test results, the decrease in the soil's LL and PI were observed at the increasing amount of added RHA. This is due to the reduction of clay particles present in the soil mixture. Clay minerals such as Montmorillonite, Illinite, and Kaolinite are responsible for the clay's high plasticity. Through the introduction of RHA, a non-plastic material, the Atterberg limits of soil mixture were improved.

Table 5 Atterberg limits test results

RHA Content (%)	Liquid Limit, LL (%)	Plasticity Limit, PL (%)	Plasticity Index, PI (%)
0	75	22	53
5	63	23	40
10	56	25	31
15	53	26	27
20	51	28	23
25	48	30	18

3.3.2 Moisture-density Relationship

The moisture-density relationship is an important property which is generally associated with soil compaction - a common practice in improving the strength characteristics and the overall stability of the soil. Table 6 presents the summarized results for the soil's maximum dry density (MDD) at optimum moisture content (OMC) obtained from Standard Compaction Test (Proctor Method). In order to consider RHA as effective in terms of improving the soil's Moisture-Density Relationship, ASTM D4609 states that it must exhibit an increase of 80 kg/m^3 in the MDD and a decrease in the OMC by 15%. A decrease in the MDD and an increase in the OMC were observed at the increasing amount of RHA added. Soil-RHA mixtures experienced a maximum decrease of 230 kg/m^3 in the maximum dry density and a 40.17% increase in the optimum moisture content. The decrease in the MDD can be attributed to the presence of RHA, which has a significantly low specific gravity. The high amount of voids present in the RHA contributed to the reduction of the soil's MDD. The increase in the OMC is due to the increased porosity of soil mixtures with RHA [12]. A significant amount of voids are present in RHA which increases the capacity of water a sample can intake. In turn, the increase of the OMC indicates that more water is needed to effectively compact the soil.

3.3.3 Unconfined Compressive Strength

The unconfined compressive strength test is a widely performed test to quickly obtain the soil's unconfined compressive strength, q_u, a strength parameter of the soil which does not consider confining pressure. Figure 6 presents the relationship between the unconfined compressive strength and the curing period. It can be observed from test results that the specimens exhibited an increase in q_u as the curing day progresses. This is due to the presence of water maintained within the samples, allowing its strength through time. A curing period of 35 days was also considered in order to analyze the soil's long-term strength development.

ASTM D4609 states that an increase of 345kPa (50 psi) in the UCS indicates that the additive is effective in improving the soil's UCS. From test results, it can be observed the soil's UCS decreases at the increasing amount of RHA added. Figure 7 presents the effect of RHA on the UCS of the soil. Due to the introduction of RHA, a non-cohesive material, the decrease in the soil's UCS was observed. The presence of RHA prevented the soil's strength to develop over time. Though RHA contains pozzolanic property, its content is not enough to produce cementitious mixture preventing the soil-RHA mixture from developing a strong chemical bond.

Table 6 Summary of moisture-density relationship

Mixture	Maximum Dry Density (MDD) kg/m^3	Optimum Moisture Content (OMC) %
Untreated Soil	1420	27.3
95% Soil + 5% RHA	1410	31.8
90% Soil + 10% RHA	1370	34.4
85% Soil + 15% RHA	1310	36.0
80% Soil + 20% RHA	1230	38.5
75% Soil + 25% RHA	1190	40.2

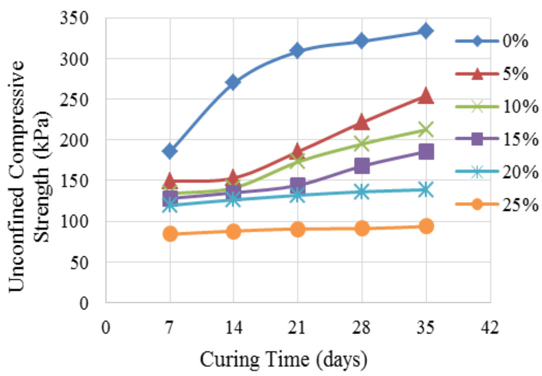


Fig. 6. Unconfined compressive strength vs. curing period

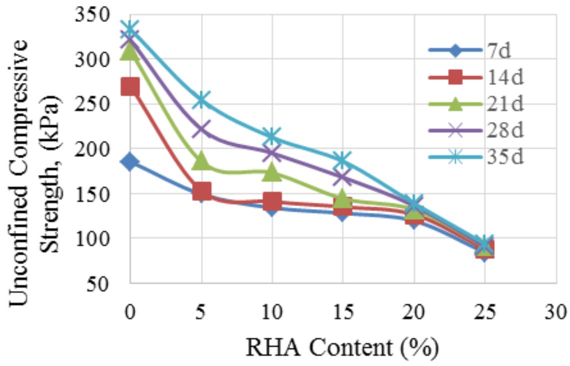


Fig. 7. Unconfined Compressive Strength vs RHA content

3.4 Predicting the Unconfined Compressive Strength

From the normalized plot of unconfined compressive strength against the varying RHA content, an equation was generated as shown in Eq. (1) that can be used to predict the unconfined compressive strength of the soil at varying RHA content. Through the use of the formulated equation, the maximum attainable strength of the 25% RHA (35-day curing period) is around 104.97 kPa, which shows a significant drop from the control specimen's 333.25 kPa strength at 35-day curing period.

$$\boldsymbol{UCS} = (474.88x^4 - 329.9x^3 + 75.751x^2 - 8.479x + 1)\,\boldsymbol{UCS_o} \quad (1)$$

where:
$\boldsymbol{UCS}$ = unconfined compressive strength at a specific x% RHA, kPa
$\boldsymbol{UCS_o}$ = unThe confined compressive strength of the control specimen at any given curing period, kPa
$\boldsymbol{x}$ = RHA content in the decimal form

3.5 Expansion Index

The expansion index (EI) test is generally performed to reveal the expansion potential of the soil based from ASTM D4829. Table 7 presents the summarized data obtained from performing the EI test. In order to determine if the RHA is effective in terms of improving the soil's expansion index, the resulting EI value must be less than 20 in order to negate its classification as expansive. Based on test results, a decreasing trend in the soil's EI was observed at an increasing amount of RHA content. In particular, soil mixtures with 20% and 25% RHA yielded EI values lesser than 20; thus, classifying it as non-expansive. The reduction in the EI value at increasing RHA content can be attributed to the RHA's high water adsorption capabilities and non-plastic behavior. As previously stated from the clay's EDX results, it was evident that it contained montmorillonite and other minerals which are responsible for the soil to swell with the presence of water. The clay's chemical composition can be linked to the soil's high plasticity and expansion index as evidently seen from the conducted test results. Through the presence of RHA, its non-plastic behavior prevented the soil from swelling despite being fully inundated in water. In addition, the RHA's high water adsorption capability was also a factor since it allowed the water to adhere, which limits the water's attraction to the clay particles.

Table 7. Summary of results for expansion index

Percentage of RHA	Mean EI value	Potential Expansion
0	111	High
5	66	Medium
10	49	Low
15	29	Low
20	12	Very Low
25	0	No Expansion

4. CONCLUSIONS

Based on the conducted study involving the treatment of expansive soils with rice husk ash, the following conclusions were formulated:

A significant decrease of about 27.23% and 33.87% in the soil's Liquid Limit and Plasticity Index respectively were observed when RHA was added in the expansive soil. This classifies RHA as effective in terms of improving the soil's Atterberg limits.

A decrease of as much as 230 kg/m^3 in the soil's maximum dry density and an increase of 47.41% in the soil's optimum moisture content were observed. This classifies RHA as ineffective in terms of improving the soil's Moisture-Density relationship.

A decrease of as much as 194.2 kPa in the soil's unconfined compressive strength was observed as the amount of added RHA increases. This classifies RHA as ineffective in terms of improving the soil's Unconfined Compressive Strength.

The addition of RHA reduced the expansion index value of the soil of as low as 0 (no expansion). Only mixtures with 20% and 25% with EI values of 12 and 0 respectively were not considered as expansive as per NSCP Section 303.5. This classifies RHA as effective in improving the expansion index of the soil specifically with 20 to 25% RHA content only

It is recommended for future work to conduct a study on RHA with other cementitious agents to find out if there will be an improvement in its compressive strength property.

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