Utilization of Agricultural Wastes in Enhancing Strength and Reducing Shrink-Swell Potential of Expansive Soils

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Utilization of Agricultural Wastes in Enhancing Strength and Reducing Shrink-Swell Potential of Expansive Soils

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Abstract: *This study determined the effects on the strength performance of expansive soil with rice husk ash (RHA) combined with coconut shell ash (CSA) as admixtures calcined at varying durations. The expansive soil sample was sourced from the proposed sanitary landfill site excavated at a depth of almost 2 meters. The expansive soil was mixed with 20% RHA as the primary stabilizing agent to control the shrink-swell potential and a varying amount of CSA as the binder to improve the strength of the expansive soil. The samples were mixed with either tap water or seawater to examine their effects on the soil's shrink-swell potential and strength. Laboratory tests like Atterberg limits, compaction by standard Proctor, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) were conducted to determine the improvement in the soil properties. All specimens showed improvement in UCS by increasing more than 345 kPa. The sample with 10% CSA and 20% RHA calcined at 10 hours showed the most significant improvement. The specimen soaked with tap water yielded higher CBR values than the specimen soaked with seawater, with 10-hour calcination. Based on the load-bearing capacity, the maximum strength improvement of expansive soil was achieved when mixed with 10% CSA and 20% RHA at 10 hours of calcination soaked in tap water.*

Keywords: Expansive soil; Calcination duration; Unconfined compressive strength; Load-bearing capacity

1. INTRODUCTION

Fine-grained soils with high plasticity are noted to be expansive. Expansive soils are known for their excessive volume shrink-swell potential. In countries with volcanic activities, expansive soils are widespread due to the deposition of volcanic ashes and pyroclastic materials. When pyroclastic materials from volcanic eruptions undergo a gradual process of weathering aided by water, this produces smectite-type clays, known to cause the expansive nature of clay soils. According to the study of Ikeagwuani and Nwonu [1], smectite clays in the soil layers caused structural problems, such as cracked foundations, floors, and basement walls. In road construction, expansive soil's shrink-swell behavior causes pavement cracking.

When soil is identified as expansive, soil treatment should be done as part of the pre-construction process. One of the possible solutions to counter the effects of expansive soil is to remove and replace it with a non-expansive one. However, this is considered an impractical way of solving the effects of expansive soil due to the additional costs involved and waste generation. Chemical soil stabilization is an alternative solution to improving soil engineering properties. It was proven by several studies that soil treated with an admixture of pozzolanic and cementitious properties like cement and lime decreased its swelling potential [2,3]. However, using cement as a stabilizing agent contributes to the rising carbon footprint of construction. Thus, it has become a trend nowadays to use waste materials exhibiting the same properties as cement as a sustainable way of soil stabilization. The use of fly ash as a substitute for cement [4,5] and for soil stabilization [6] has gained the attention of several researchers. Several studies proved that agricultural wastes like rice husk ash (RHA) and coconut shell ash (CSA) contain pozzolanic properties, making them suitable supplementary cementitious materials [7, 8, 9]. The addition of RHA proved effective in mitigating the swelling potential of expansive soils. Adding 20% to 25% of rice husk ash (RHA) in the soil mixture reduced the shrink-swell potential of expansive soil. However, results showed that there had been no significant effect in terms of the strength properties of the soil [10]. As the soil undergoes a shrink-swell cycle, it loses its strength during repeated volume changes [11]. It was recommended that a binding agent should be used with RHA to enhance its quality and efficiency as a soil stabilizer. CSA contains a pozzolanic property, making it ideal as a binding agent.

The process of calcination produces rice husk ash and coconut shell ash. The calcination process and duration affect the formation of the different types of silica, such as carbon silica, crystalline silica, and amorphous silica. Fast open-air burning produces carbon silica, whereas slow-burning and combustion produce crystalline silica [12]. The temperature of 500ºC to 800ºC led to the formation of amorphous silica, which is desired for most engineering purposes due to having the best reactions for improving soil strength properties. Bie et al. [13] reported that rice husks calcined at 600°C were mainly composed of amorphous silica, while those at 700°C started to form crystalline silica. Isberto et al. [14] also reported that rice husks calcined for ten hours at temperatures ranging from 400°C to 600°C were mainly amorphous in a form with highly pozzolanic properties when reacted with water. Depending on the type of silica formed, the pozzolanic reaction's effect on soil strength properties may vary. Hydration reaction with amorphous silica leads to a chemical reaction that causes the formation of Calcium Silicate Hydrate (C-S-H) gel that contains cementitious properties.

The type of water used in the soil mixing is another factor considered in this study. Past research has shown that the different kinds of water substantially affect the results of the geotechnical properties of the soil, some of which are tap water, distilled water, and seawater [15]. Previous studies have used seawater in the soil mixing method because of its abundance and the presence of sodium and chloride that affect the hydraulic activity responsible for the volumetric change of the expansive soil [16]. The results showed that seawater creates a better reaction to form Calcium Silicate Hydrate (C-S-H) gel, a hardening gel formed by pozzolanic reactions.

This study investigates the effects on the strength performance of expansive soil with rice husk ash (RHA) and coconut shell ash (CSA) as admixtures calcined at varying durations. The calcination duration was varied to determine the appropriate time to produce the highest amount of amorphous silica that would improve the stabilized soil's strength. The study also aims to determine the type of water to be used for curing that would enhance the strength of the stabilized soil.

Treatment of expansive soils has been expensive due to the processes involved, like soil replacement and partial soil replacement with cement and other chemical stabilizing agents. This study offered a cheaper way of controlling the shrink-swell behavior of expansive soil. At the same time, it hoped to help address the waste disposal problem of the agricultural industry. This study's positive attributes of the soil, RHA, and CSA mixture would hopefully encourage future studies to investigate other practical yet valuable applications of these agricultural wastes. Incorporating seawater in the mixing process could pave the way for its potential application in the construction industry, which is particularly beneficial for countries facing water shortages and drought. This study also contributes to understanding how stabilized soil behaves when subjected to high-salinity water conditions.

2. MATERIALS AND METHODS

2.1 Preparation of Rice Husk Ash and Coconut Shell Ash

The rice husks and coconut shells were obtained from local farmers in Northern Luzon, Philippines. The rice husks and coconut shells each underwent calcination using a homemade fire chamber with temperatures ranging from 400°C to 600°C for 8 and 10 hours. Scanning Electron Microscopy determines the microstructure and morphology of both RHA and CSA. The X-ray Diffraction (XRD) test determines the crystallographic structure of the ashes and aids in identifying whether the formed silica is amorphous or crystalline.

2.2 Source of Sea Water

The seawater was obtained from natural seawater in Zambales, Philippines. The study used a water filter or strainer to ensure the seawater was free from visible organic materials. Seawater was obtained from the source within the week of its usage to prevent spoilage.

2.3 Soil and Admixtures

The fine-grained soil used in this study was sourced from Kauswagan, Lanao del Norte, Philippines, the site intended for a sanitary landfill project [17]. The sample was taken from the site at a depth of at least two (2) meters to exclude organic matter. This study was done using the soil from the sanitary landfill project site to explore the possibility of improving its strength properties so that it can be used for other geotechnical applications. The soil is the same as the soil used in the study of Tan and Adajar [18] and Adajar et al [19], which was proven expansive. The soil mixture in this study was made up of pure soil, 20% RHA as the primary stabilizing agent to control the shrink-swell potential, and a varying amount of CSA as the binder to improve the strength properties of the soil. According to the study of Adajar et al. [10], the optimum amount of RHA to control the expansive nature of the soil was 20%. The CSA was added to the soil-RHA mixture at 5% and 10% replacement by volume. The design mix proportion is shown in Table 1 using ashes that were calcined for 8 hours and 10 hours. Table 2 shows the test programs in this study for each mix proportion. All tests were done following the ASTM Standards.

The soil mixture was prepared in two batches. The first batch was cured with tap water and the other with seawater. The use of seawater in the curing method was made to investigate the behavior of the stabilized soil when exposed to high-salinity water conditions. The samples were kept in a sealed container for at least 16 hours before tamping into the mold. The specimens underwent air curing for 16 days before subjecting to unconfined compression tests as per ASTM D2166. The mix proportion that produced the highest UCS values was subjected to additional UCS tests at the curing period of the 5th, 16th, and 26th days to evaluate the strength development of the soil mixture. A California Bearing Ratio (CBR) test was performed on the mix proportion that produced the highest UCS with specimens soaked in tap water or seawater to determine its load-bearing capacity.

Table 1. Soil mix proportions

Pure Soil (%)	CSA (%)	RHA (%)
100	0	0
80	0	20
75	5	20
70	10	20

Table 2. Test program on soil mixture

Tests performed	Materials
Index Properties (Specific gravity, Grain-size analysis, Atterberg Limits)	Pure soil
SEM and XRD	RHA and CSA
UCS of specimens cured in tap water and seawater for 16 days	Pure soil, 00C20R08H, 00C20R10H, 05C20R08H, 05C20R10H, 10C20R08H, 10C20R10H
UCS of specimens cured for 5, 16, and 26 days	Pure soil and the specimen with a mix proportion that produces the highest UCS value.
CBR test of specimens soaked in tap water and seawater	Pure soil and the specimen with mix proportions that produce the highest UCS value.

Note: C – Coconut shell ash; R – Rice husk ash; H – Hour of calcination. 10C20R10H means a mixture of soil with 10% coconut shell ash and 20% rice husk ash with ashes calcined at 10 hours.

3. TEST RESULTS

3.1 Index Properties and Expansion Index of Fine-grained Soil

Table 3 shows the index properties of the soil used in this study. The soil is classified as high plasticity silt with the USCS group symbol of MH and is predominantly composed of fine particles. The soil's average expansion index (EI) is 98 [18]. According to the National Structural Code of the Philippines (NSCP) [20], the soil is considered expansive if the liquid limit and plasticity index are greater than 50% and 15%, respectively, and the expansion index is greater than 20. Results of the Atterberg limits test and EI values surpassed the minimum criteria set by NSCP, thus proving that the soil used in this study is expansive.

Table 3. Index properties of soil

	Index Values
Specific Gravity, Gs	2.414
Passing No. 200 sieve (%)	98
Liquid Limit, LL (%)	73
Plastic Limit, PL (%)	47
Plasticity Index, PI (%)	26
Soil Classification (USCS)	MH – High Plasticity Silt
Expansion Index [18]	98

3.2 Microstructure of RHA and CSA

Figures 2 and 3 show the micrographs of RHA taken after 8-hr and 10-hr calcination, respectively. At 500x magnification, the microstructure appears to be porous and sponge-like. The spongey, coral-like, and porous shape of the microstructure showed similarity to the microstructure in the study of Daud et al. [21], where RHA yielded an 85 to 90% amorphous silica. At 1500x magnification, the particles appear flat, smooth and interlocked. The voids seemed irregular with a web-like pattern, which showed a close imitation of the grounded RHA with amorphous silica in the study of Sandhu and Siddique [22].

The microstructures of CSA at both eight hours and ten hours of calcination are presented in Figures 4 & 5, respectively. It can be noted that the microstructure of the CSA calcined at eight hours and ten hours showed similar results. At lower magnification (500x), the particles appeared to be clustered. At higher magnification, the particles showed interlocking particles with voids of varying size and pattern. Particles remained closely packed and linked even at a longer calcination time. From the studies of Satheesh et al. [23] and Panda et al. [24], the irregular shape of CSA can be observed to remain the same despite different calcination methods.

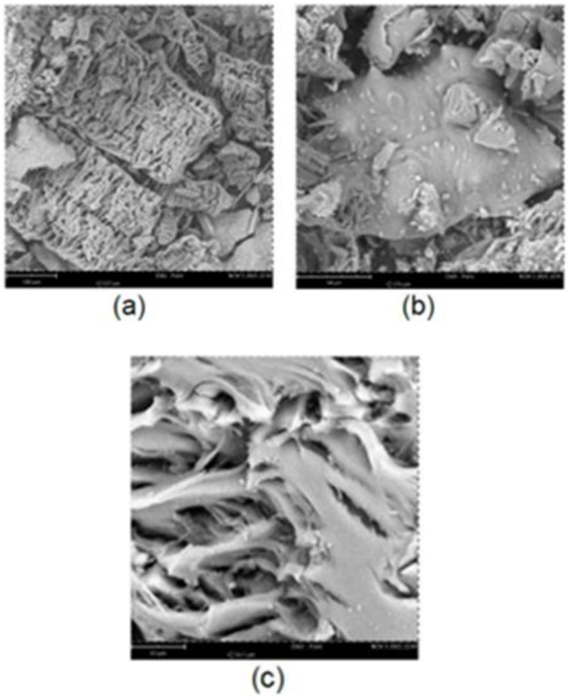


Fig. 2. SEM results of RHA calcined for 8 hours at a magnification of (a) 500x, (b) 1500x, (c) 5000x

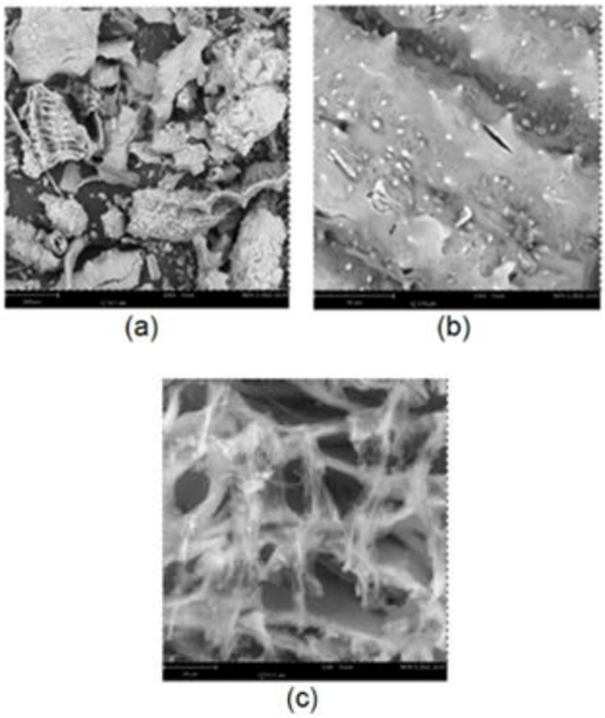
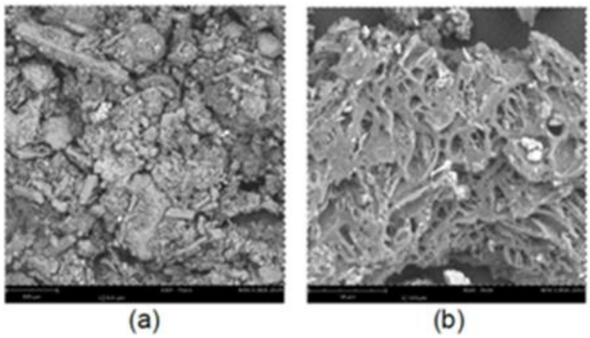


Fig. 3. SEM results of RHA calcined for 10 hours at a magnification of (a) 500x, (b) 1500x, (c) 5000x



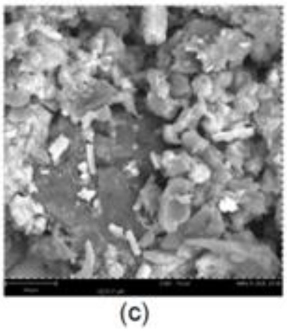


Fig. 4. SEM results of CSA calcined for 8 hours at a magnification of (a) 500x, (b) 1500x, (c) 5000x

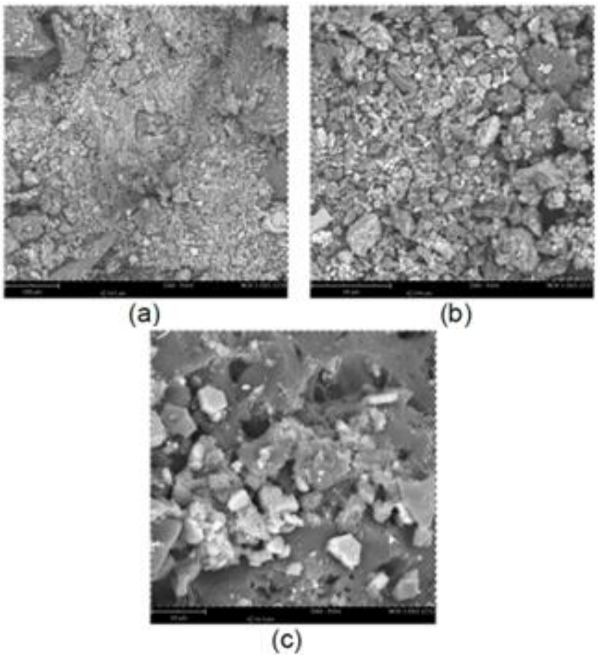


Fig. 5. SEM results of CSA calcined for 10 hours at a magnification of (a) 500x, (b) 1500x, (c) 5000x

The X-ray diffraction (XRD) of both CSA and RHA determines its crystallographic structure to help categorize the nature of the material, whether it is crystalline or amorphous. Figures 6 and 7 present the XRD pattern observed from RHA and CSA, respectively. At both calcination durations, the diffraction pattern of RHA showed a broad, featureless peak, which fits the description of amorphous silica in the study of Fleck et al. [25]. Comparing this with the investigation by Shabir et al. [26] on different types of silica to varying kinds of calcination temperatures, the XRD pattern of RHA at both 8 hours and 10 hours of calcination followed the trend of amorphous silica. Figure 7 presents the XRD pattern of CSA. The amorphous silica formed with CSA was not entirely the ideal type of amorphous silica. This result may be attributed to a few peaks with short widths representing short amounts of crystalline silica. Silica, which is amorphous in form, possesses highly reactive pozzolanic properties when mixed with water. The amorphous compound induced a chemical reaction that caused the formation of Calcium Silicate Hydrate (C-S-H) gel that contained cementitious properties, which is the desired property of a binder agent.

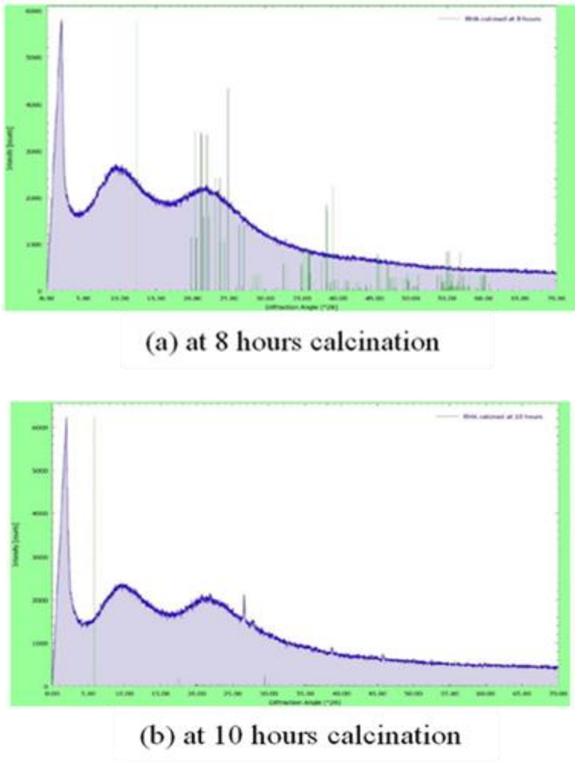


Fig. 6. XRD patterns of RHA

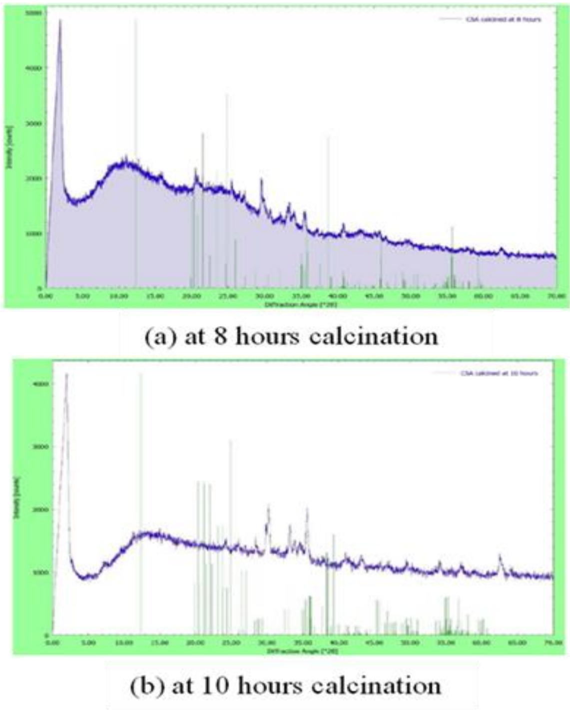


Fig.7. XRD patterns of CSA

3.3 Unconfined Compressive Strength (UCS)

The unconfined compressive strength is the load per unit area that a cylindrical soil sample undergoes until the soil fails. For the admixture to be effective, the soil mixtures must display an improvement in unconfined compressive strength of at least 345 kPa (50 psi) or greater, as indicated in ASTM D 4609 [27]. Figure 8 shows the averaged unconfined compressive strength for every percentage of CSA mixtures. All soil mixtures reported an increase of more than 345 kPa, with seawater curing exhibiting an increasing trend of UCS with the addition of CSA. The highest unconfined compressive strength was the 10C20R08H and 10C20R10H, cured with seawater, with a value of 2092 kPa. The greater strength when cured with seawater can be attributed to some seawater ions that caused soil particles' flocculation. Flocculation binds the clay particles together to become more compact, preventing water from being absorbed. As the clay particles become closely packed, the free swell volume decreases, and the unconfined compressive strength increases [16]. On the other hand, soil samples cured with tap water reached maximum strength at 5% CSA addition before gradually decreasing. According to Segun & Oluyemisi [28], the decrease in strength with the addition of CSA meant that the additional percentages could have caused a weak bond between the soil and cementitious compounds.

The mixture with the highest UCS (10C20R10H cured in seawater) was subjected to longer curing days to investigate the strength development and its long-term strength performance. Table 5 presents the results of UCS at every curing period compared with pure soil. It can be noted that the extended curing period in seawater led to a decrease in strength. Though it was mentioned in previous studies that saline in water aids in controlling the expansive behavior of soil [15,16], prolonged exposure of the soil stabilized with RHA and CSA to water with high salinity can alter the chemical reactions between stabilizing agents and the soil. The presence of high concentrations of ions such as sodium (Na+) and Chloride (Cl-) found in seawater can replace the calcium ions in the stabilized soil matrix, leading to the dispersion of soil particles [29]. This can disrupt the pozzolanic reactions that contribute to soil stabilization, weakening the bonds formed between the soil particles and the ash components. This can be remedied by adding calcium-based stabilizers, such as gypsum or calcium chloride, that can help counteract the dispersive effects of sodium ions from saline water [29]. Adding other pozzolanic materials like silica fume or metakaolin can help increase the chemical resistance and overall strength of the stabilized soil [30].

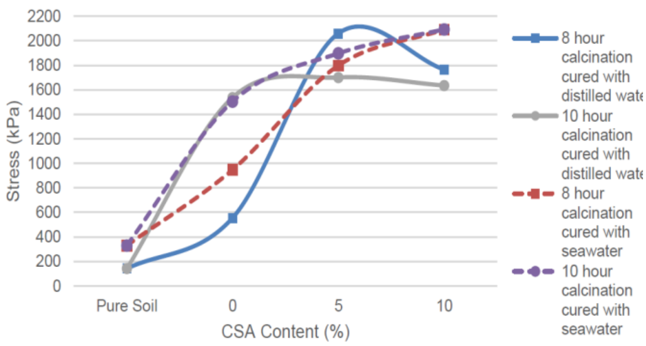


Figure 8. Unconfined compressive strength of soil-RHA with varying CSA content

Table 5. Unconfined compressive strength of soil with 10% CSA and 20% RHA at every curing period

Mixture	UCS (in KPa)		
	5th-day curing	16th-day curing	26th-day curing
Pure soil	223	331	1534
10C20R10H cured in seawater	916	2092	1242

3.4 Load-Bearing Capacity

The proportion that yielded the highest UCS values was subjected to a CBR test to determine its load-bearing capacity. Tests were conducted on pure soil, 10C20R, for 8-hours and 10-hours calcination. Tap water and seawater were used to soak the soil sample. The soak condition of the sample simulates the environmental condition of the soil during events such as extreme rainfall and flooding. The seawater used in the study was utilized for strength development and to supplement the RHA in controlling the shrink-well potential of expansive soil. Past research has used seawater in soil mixing to reduce the shrink-swell potential. Studies attributed this to the abundance of sodium and chloride it contains. As shown in Table 6, all soil mixtures showed a higher CBR value than pure soil. Adding admixtures (RHA and CSA) produced positive soil load-bearing capacity results. The positive effect of calcination duration can also be noted in the results, with 10 hrs calcination having higher values of CBR. The mixture of 10% CSA and 20% RHA calcined at ten hours and soaked in tap water exhibited the best strength performance. The CBR values were evaluated using the criteria set by Bowles [31], as shown in Table 7. The values obtained satisfy the criteria for the material's suitability as a base or subbase material with a rating of good, while the soil mixture with ash calcined for 8 hrs. satisfies the criteria for subbase material in road construction with a fair rating.

Table 6. California bearing ratio (CBR) test results

Mixture	CBR, when soaked in tap water	CBR, when soaked in seawater
Pure soil	3.2	4.1
10C20R08H	18	14
10C20R10H	46	24

Table 7. Soil ratings for road construction [31]

CBR (%)	Rating	Uses
0 - 3	Very poor	Subgrade
3 - 7	Poor to Fair	Subgrade
7 - 20	Fair	Subbase
20 - 50	Good	Base or Subbase
> 50	Excellent	Base

4. CONCLUSIONS

The fine-grained soil used in this study, classified as high plasticity silt with group symbol of MH, exhibited high values of liquid limit and plasticity index, considered expansive soil. The microstructure of RHA calcined at eight and ten hours showed a porous and sponge-like structure. The microstructure of CSA calcined at eight and ten hours manifested a clustered and irregular structure. X-ray diffraction (XRD) tests showed that the 8-hr and 10-hr calcination of RHA and CSA resulted in the formation of amorphous silica.

The calcination for 8 hrs. and 10 hrs. of RHA and CSA improved the unconfined compressive strength (UCS) of the stabilized soil cured in tap water and seawater. The maximum UCS value of 2092 KPa was observed at 10C20R10H mixture cured in seawater; however, there is a decrease in strength in the long-term curing period. It can be concluded that exposure to seawater for an extended period is not desirable for the expansive soil stabilized with RHA and CSA, as this can weaken the bonds between the soil particles and the ash components. The mix proportion of 10C20R at both 8-hour and 10-hour calcination was subjected to a CBR test to determine its load-bearing capacity. The maximum CBR values are obtained from the soil mixture soaked in tap water, yielding CBR values of 18 and 46 when using ashes calcined for 8 and 10 hours, respectively. The result showed that the strength improvement in CBR value was ideal at 10 hours of calcination. It was observed that 10C20R10H yielded acceptable CBR values, which satisfies the base or subbase materials criteria for pavement. Based on load-bearing capacity, it can be concluded that the maximum strength improvement of expansive soil can be achieved when mixed with 10% CSA and 20% RHA at 10 hours of calcination and soaked in tap water. Using admixtures with 8-hour calcination can be possible if the soil mixture is intended to be used as subbase materials only.

The study proved an improvement in stabilized soil's unconfined compressive strength and load-bearing capacity when the admixtures (RHA and CSA) are calcined for 8 hours or more.

It is recommended for future studies to verify if the addition of pozzolanic materials or calcium-based stabilizers can improve the strength of the soil mixture exposed to seawater. It is also advisable to evaluate the durability and performance across diverse environmental conditions to guarantee its resilience in various scenarios.

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