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Research article

Stabilization of Sandy Soil with High Salinity Conditions using Rice Husk Ash and Gypsum to Improve Physical and Mechanical Properties

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Abstract: Sandy soil is a non-cohesive type with no binding force among particles. Non-cohesive soils have loose grains and are not solid. In high-water level conditions, the sandy soil changes its properties to liquid, causing the cohesion value between grains and its shear strength to be lost. This condition can damage civil structures, such as collapse and construction failure. Therefore, soil improvement is carried out by adding rice husk ash and gypsum, which contain SiO_2 and $CaSO_4.2H_2O$, to bind sand grains. Soil samples were tested by comparing the magnitudes of the cohesion values and the internal shear angles through direct shear tests. The mixing percentages for rice husk ash were 5%, 10%, and 15%, and for adding gypsum was 5%, with curing times of 3 days, 7 days, and 14 days (about 2 weeks). The soil sample used was sandy soil from Congot Beach, Yogyakarta, which has poorly graded sand. The optimal content for improving sandy soil was to use 5% gypsum and add 10% rice husk ash, which was proven to increase the carrying capacity of the soil. This improvement was evidenced by an increase in cohesion from the initial value of 0.029 to 0.061 and a change in shear angle from 19.82° to 29.18° in the sample taken after 14 days (about 2 weeks). The bonding observed due to stabilization was confirmed using the results of X-ray diffraction (XRD) and scanning electron microscopy (SEM).

Keywords: Gypsum; Rice husk ash; Saline soil; Soil stabilization

1. Introduction

The sandy soil at Glagah Beach, located east of Congot Beach, shows that Glagah Beach sand belongs to group S with a poor gradation classification and contains few fines, with a percentage of soil that passes sieve no 200 of 0.058%. The sampling location was on the coast, with the highest salinity level of 3.4%. Sandy soil is a type of soil that is non-cohesive (cohesionless soil) [1]. Non-cohesive soils, such as sandy soils, do not have the binding power among particles [2]. According to [3], in the technical sense of the term, soil carrying capacity is the ability of the soil to carry or resist settlement due to loading, namely the shear resistance spread by the soil along its shear planes.

The magnitude of the shear-bearing capacity of a layer of soil is affected by the soil cohesion value, the internal shear angle, the soil's unit weight, and the soil's pore pressure [4]. Non-cohesive soil with loose granules and not dense in high water conditions can act as a viscous liquid. Liquefaction transforms granular materials from solid to liquid due to increased pore water pressure and loss of effective stress [2]. When the soil is loose, and a loss of soil shear strength will accompany changes, this condition can cause damage to civil structures, such as building collapse [5]. Soil stabilization is a soil engineering method that aims to improve and maintain specific soil properties to meet technical requirements. Stabilization in sandy soil is carried out to increase sand's bearing capacity and shear strength [6, 7]. In previous research, no one has discussed the effect of salinity on stabilization tests with rice husk ash. This research aims to find out how salinity affects soil strength after stabilization because the sample location is on the south coast of Yogyakarta.

2. Materials and Methods

Rice husk ash is formed through the carbonization of husks, and for optimal bonding, it requires an additional step known as activation [6, 8]. Several factors, such as the activating agent and immersion time, influence the chemical activation process. Adding the activating agent helps remove impurities and enhance the absorbent quality. During the burning of rice husks, compounds like hemicellulose and cellulose are converted into CO_2 and H_2O. The resulting ash is whitish due to the burning process of rice husks. The primary component of husk ash is silica, but it also contains other compounds, as shown in Table 1.

Table 1 Chemical components of rice husk ash

Components	Percentage content (%)
SiO_2	94,4
Al_2O_3	0,61
Fe_2O_3	0,03
CaO	0,83
MgO	1,21
K_2O	1,06
Na_2O	0,77
SO_3	-

Source: Folleto (2006)

Gypsum is calcium sulfate hydrate ($CaSO_4$ $2(H_2O)$), a sulfate mineral found on the earth [9, 10]. Gypsum can enhance soil stability as it contains calcium, which binds organic matter and increases the water seepage rate. Moreover, gypsum can be readily hydrated by rice husk ash, the residue from burning rice husk, which has a high silicate element with a pozzolanic activity index of 87%, enhancing the permeability of the soil mixture. In this research, 5% gypsum was added to all samples.

The sampling was at Congot Beach in Jangkaran Village, Temon District, Kulon Progo Regency. The location for taking sand samples was at coordinates 7.9026197 110.0397730, with a sampling undisturbed depth of 20 cm (about 7.87 in) from the surface. The sampling location can be seen in Figure 1.

Rice husk ash, on the other hand, was subjected to various percentages within the mix, specifically 5%, 10%, and 15% of the weight of sandy soil. These different ratios of rice husk ash were systematically employed to investigate how they influenced the overall composition and performance of the soil mixture. By varying the amount of rice husk ash, researchers aimed to understand the optimal ratio that would enhance the desired properties and characteristics of the mix, ultimately contributing valuable insights for various applications in construction [11, 12].

The soil stabilization process involved mixing the initial sand soil sample with a predetermined percentage of gypsum and rice husk ash, with an initial water content of 6.12%. The rice husk ash was sifted using a No. 50 sieve to achieve a finer particle size, facilitating the effective filling of pore cavities in sandy soils. Adding gypsum and rice husk ash for each variation aims to achieve uniform mix content. The sand, gypsum, and rice husk ash were combined based on calculated weights for each mixture percentage, followed by aging in a sealed container for 3 days, 7 days, and 14 days (about 2 weeks). For each condition, 3 samples of test objects were made, and then the average test results was taken. Figure 3 illustrates the mixing and curing procedure.

Figure 1 Congot Beach, in Jangkaran Village, Temon District, Kulon Progo Regency

a) b) c)

Figure 2 Mixed material for sand soil stabilization experiments sandy soil, b) rice husk ash, c) gypsum powder

a) b)

Figure 3 The mixing process for the sand soil stabilization experiment, a) the process of mixing the stabilizing agent and b) Curing the specimen

The process of stabilization mixing, as depicted in Figure 3, was carried out using the water content determined to be optimal through the Proctor test. The optimum water content (OMC) value was 26%. Subsequently, the sample underwent a curing treatment at a room temperature of 25°C.

A direct shear test was conducted on sandy soils to determine the soil's cohesion value and shear angle under study. The standard used in this direct shear test was SNI 03-3420-2016, "Method of Direct Shear Strength Test of Unconsolidated and Undrained Soil" [13]. A direct shear test was carried out on each specimen for each mixture percentage. Initially, the test object was molded into the ring, and then the weight of the ring + the test object was measured by pressing the ring into the test object, which can be seen in Figure 4. After that, it should be assembled into the direct shear testing box and loaded [14].

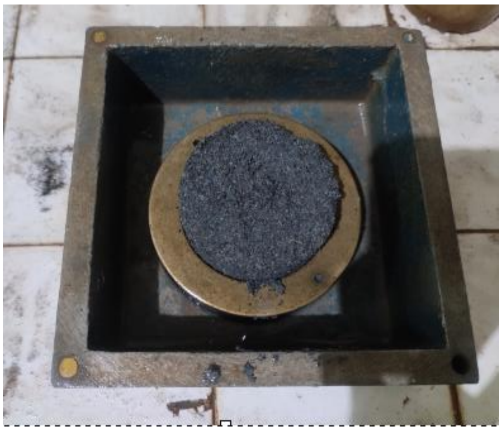


Figure 4 Direct shear test

3. Results and Discussion

3.1 Direct Shear

The analysis of the direct shear initial soil test results showed that the initial soil cohesion value was 0.029 kg/cm^2, and the internal shear angle was 19.82°. Following curing for 3, 7, and 14 days (approximately 2 weeks), the results indicated an increase in cohesion and shear angle.

Based on Figure 5, the addition of varying levels of rice husk ash and gypsum has been shown to increase the carrying capacity of the soil, as seen from the increase in the soil cohesion value. There was a slow increase in the variation of the mixture of 5% rice husk ash + 5% gypsum, followed by the rise in the mix of 10% rice husk ash + 5% gypsum. However, the variation in the content of the mixture of 15% rice husk ash + 5% gypsum began to decrease, based on strength cohesion and shear angle test.

The increase in cohesion value observed in this context can be attributed to the cementation reaction during the curing time. As the soil matures, a chemical reaction occurs between the calcium (Ca) present in gypsum and the silicate (SiO_2) and aluminum (Al_2O_3) in rice husk ash. This reaction was graphically represented, illustrating a noticeable surge in the soil's cohesion value post-curing time [11].

This reaction's significance lies in enhancing the soil's structural integrity. Calcium, silicate, and aluminum combine to form stable compounds that effectively bind the soil particles, increasing cohesion. This improved cohesion is vital for various applications, such as construction and geotechnical engineering, where the strength and stability of the soil are critical factors. In summary, the cementation reaction between gypsum, silicate, and aluminum in rice husk ash is pivotal in enhancing soil cohesion, making it a valuable process for soil improvement and engineering. Regarding the testing after 14 days (about 2 weeks) of age, there may still be an increase in the shear strength of the soil, but the humidity level will further decrease, causing cracks in the sample and resulting in a decrease in strength when the sample becomes too brittle. This prompts a need for further research to carry out tests with a longer curing age of 14 days (about 2 weeks) and determine the brittle point of the sample.

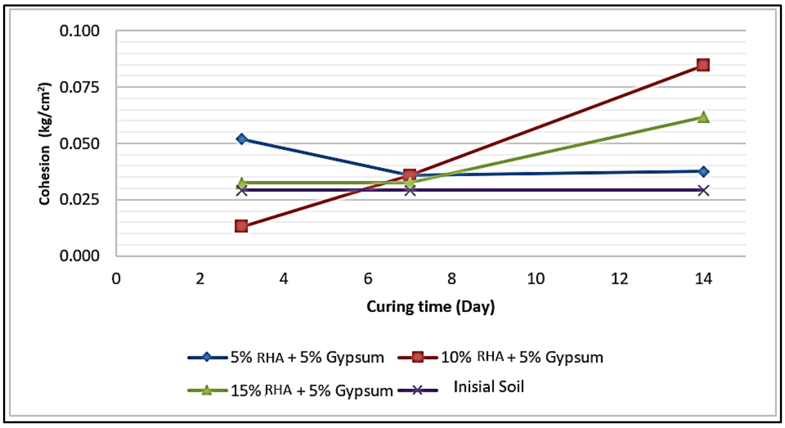


Figure 5 Graph of the effect of curing time on the cohesion value in the direct shear test

The percentage of added rice husk ash and gypsum significantly affected the increase in soil strength. A large percentage of the mixture did not necessarily result in the highest growth in cohesion, as shown in the percentage addition of 15% rice husk ash + 5% gypsum. This condition happened because the effect of the lime (Ca) reaction on the silicate (SiO_2) and aluminum (Al_2O_3) content was insufficient to support the pozzolanic reaction. Low calcium (Ca) gypsum levels made the bonds between granules not optimal [7].

The opposite occurred with the percentage of the mixture of 5% rice husk ash + 5% gypsum at different levels. The mixture did not increase the highest cohesion value because the silicate (SiO2) and aluminum (Al2O3) content in the rice husk ash was too low to react with lime in the gypsum.

The optimal mix level variation occurred at the percentage addition of 10% rice husk ash + 5% gypsum. The balanced calcium, silicate, and aluminate content reacted well with a mixture of 10% rice husk ash and 5% gypsum. It was aged for 14 days (about two weeks) so that the contents in rice husk ash and gypsum could bind soil particles better, and soil strength increased, as shown in Figure 6.

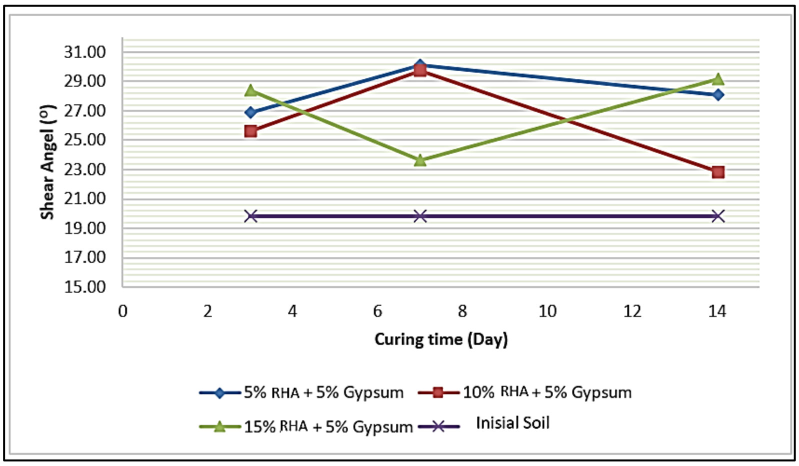


Figure 6 Graph of the effect of curing time on the internal shear angle in the direct shear test

Determining the amount of mixture percentage and the length of curing time was carried out using the trial-and-error method with variations in the mixture percentage based on previous journals regarding combinations of variations in mixing for stabilization [15][16]. A slow increase occurred in the variation of the mixture of 5% rice husk ash + 5% gypsum, and then it increased in the variation of the mix of 10% rice husk ash + 5% gypsum. However, the variation in the content of the mixture of 15% rice husk ash + 5% gypsum began to decrease based on strength cohesion and shear angle test. It can be concluded that adding husk ash can increase the binding force between particles because in rice husks, SiO_2 is 94.4%. The table of normal stress and shear stress for each mixture in sandy soil is shown in Table 2 below.

Table 2 Table of average shear stress to normal stress on direct shear testing of native soil with the addition of rice husk ash and gypsum

Day	Variation	Shear Stress (kg/cm²)		
		0,25	**0,50**	**1,00**
		Normally Stress (kg/cm²)		
3 Day	Initial Soil	0,097	0,188	0,370
	Initial Soil + 5% RHA + 5% gypsum	0,182	0,305	0,565
	Initial Soil + 10% RHA + 5% gypsum	0,084	0,266	0,461
	Initial Soil + 15% RHA + 5% gypsum	0,123	0,253	0,539
7 Day	Initial Soil	0,097	0,188	0,370
	Initial Soil + 5% RHA + 5% gypsum	0,162	0,318	0,604
	Initial Soil + 10% RHA + 5% gypsum	0,149	0,305	0,591
	Initial Soil + 15% RHA + 5% gypsum	0,143	0,247	0,474
14 Day	Initial Soil	0,097	0,188	0,370
	Initial Soil + 5% RHA+ 5% gypsum	0,136	0,335	0,552
	Initial Soil + 10% RHA + 5% gypsum	0,156	0,344	0,526
	Initial Soil + 15% RHA + 5% gypsum	0,195	0,351	0,617

Figure 7 shows the normal stress relationship with the shear stress of the initial sandy soil and sandy soil with a mixture of rice husk ash and gypsum at each curing time.

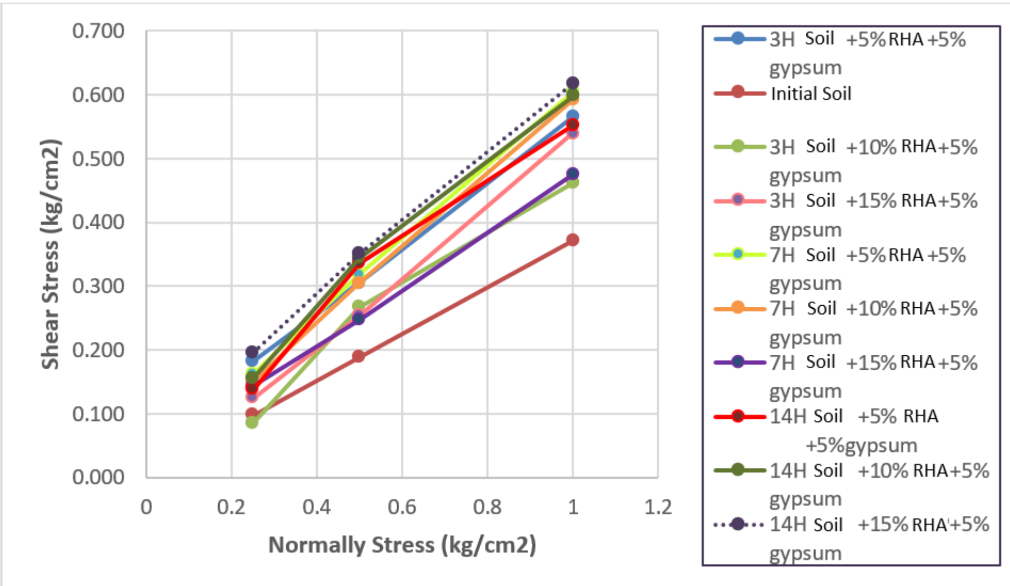


Figure 7 Graph of the effect of curing time on the internal shear angle in the direct shear test

The data presented in Figure 7 highlights a notable trend in the normal stress versus shear stress of various mixture combinations. Specifically, an increase is observed across all mixtures over time. However, the most substantial increase is observed in the mixtures featuring 5% gypsum and 15% rice husk ash.

3.2 XRD and SEM Test Result

The samples in the XRD test were taken from the highest test results with a combination of the initial soil + 15% RHA + 5% gypsum in curing for 14 days (about 2 weeks). This shows that the level of chemical bond performance has occurred optimally, resulting in the soil having the highest shear strength. Besides the elemental composition, knowing the crystallinity of SiO_2 is necessary because it is related to the synthesis process. Crystallinity analysis was performed with an X-ray diffraction instrument. The following is a diffractogram of the results analysis by X-ray diffraction shown in Figure 8.

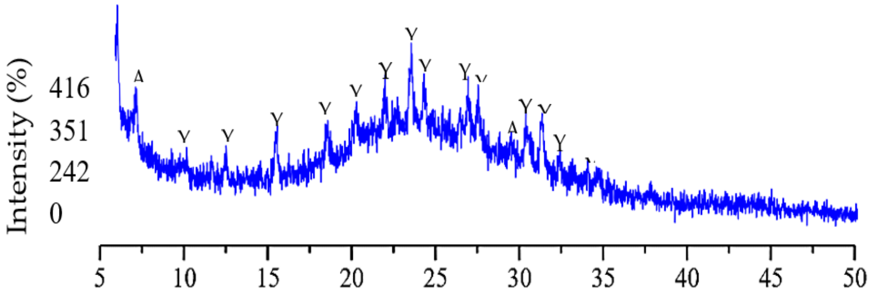
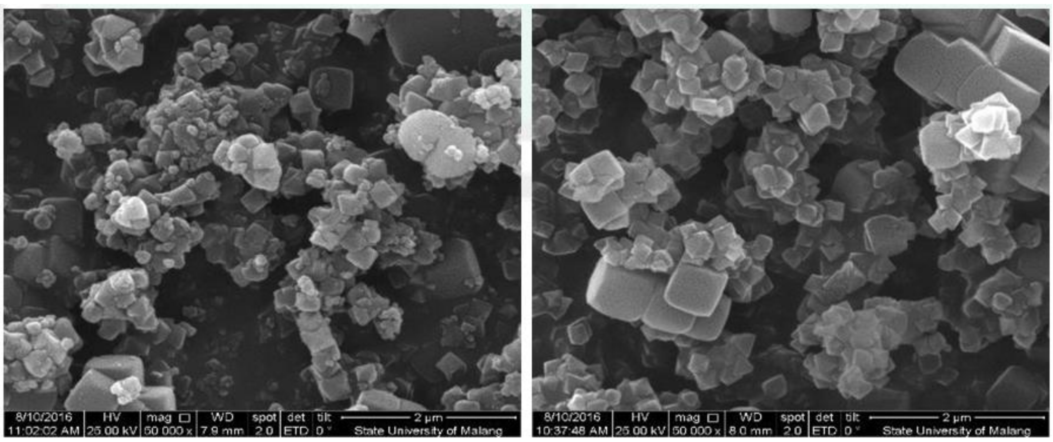


Figure 8 XRD test result

The SiO_2 diffractogram from rice husk ash with peaks in the 2ø range of 20 – 30° had low intensity, indicating that the SiO_2 phase from rice husk ash was amorphous. Amorphous silica has an arrangement of atoms and molecules in random and irregular patterns, making it more reactive than crystalline silica under various conditions [10, 12]. Therefore, rice husk ash silica can be used as a source of silica in the synthesis of Y nano zeolite [17].

Based on Figure 8 of the synthesized Y nano zeolite with variations in curing time, the crystallinity was higher the longer the curing time. At 14 days (about 2 weeks) of curing time, the synthesized Y nano zeolite had a high purity of 100%. The highest purity of Y nano zeolite was produced at 14 days (about 2 weeks) with 100% purity, but the resulting peak intensity was low. Therefore, there was a possibility of forming zeolite A and zeolite Y from the cementation. The formation of nano zeolite A was due to the synthesis of zeolite Y, which was very sensitive to pH; an increase in relatively high pH can cause the formation of zeolite A [12].

SEM characterized the surface morphology of the Y nano zeolite crystals formed. The SEM characterization results of the Y nano zeolite at curing times of 7 and 14 days (approximately 2 weeks) are illustrated in Figure 9.



a) b)

Figure 9 SEM test result 7- and 14-days curing, a) zoom 25000x, b) zoom 50000x

SEM characterization in Figure 9 showed the presence of cubic crystals for a curing time of 7 days and 14 days (approximately 2 weeks). At 7 days of curing, the size of the cubic crystals was smaller. It appeared more homogeneous, while at 14 days (approximately 2 weeks) of curing, the size of the cubic crystals was more significant and appeared slightly less homogeneous. This was also supported by the XRD results, where the crystallinity peak was lower at 7 days of curing time, and the particle size was smaller than 14 days (approximately 2 weeks). The size of the cubic crystals at 7 days of curing was calculated using the Debye Scherrer equation and ranged from 26 - 42 nm, while at 14 days (approximately 2 weeks) of curing, it ranged from 20-95 nm [18].

4. Conclusions

The SEM characterization in Figure 9, at both 7 and 14 days (approximately 2 weeks) of curing time, revealed the presence of cubic crystals. At 7 days of curing, the cubic crystals appeared smaller and more homogeneous, whereas at 14 days (approximately 2 weeks), the crystals were more extensive and slightly less homogeneous. These observations were consistent with the XRD results, indicating a lower crystallinity peak at 7 days of curing and a smaller particle size than at 14 days (about 2 weeks). Calculations using the Debye-Scherrer equation estimated the size of the cube crystals to range from 26 to 42 nm at 7 days of curing and 20 to 95 nm at 14 days (approximately 2 weeks) of curing. At 14 days (about 2 weeks) of curing time, the synthesized Y nano zeolite exhibited a high purity of 100%. The highest purity of Y nano zeolite was achieved at 14 days (about 2 weeks) of age with 100% purity, but the resulting peak intensity was low. Consequently, there was a possibility of forming zeolite A and zeolite Y from SBU. The formation of nano zeolite A was attributed to the synthesis of zeolite Y, which was highly sensitive to pH; a relatively high increase in pH can lead to the formation of zeolite A. SEM characterization revealed the presence of cubic crystals at both 7 days and 14 days (about 2 weeks) of curing time. At the 7-day curing time, the size of the cubic crystals was smaller and more homogeneous, whereas at the 14-day curing time, the size of the cubic crystals was larger and relatively more homogeneous. These observations corresponded to XRD results, which showed lower crystallinity peaks at 7 days of curing and smaller particle sizes than at 14 days (about 2 weeks). The size of the cubic crystals at 7 days of curing was estimated using the Debye Scherrer equation to be within the range of 26 - 42 nm, while at 14 days of curing, it ranged from 20-95 nm.

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