Effect of Rice Husk Ash Addition on Geotechnical Characteristics of Treated Residual Soil


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Abstract: Residual soil is commonly used as medium for foundation or material for constructions. Its low strength characteristic is attributed to weakly bonded structure inherited from parent rock and/or resulting from secondary crystallization during weathering. Soil stabilization is a common practice in attempt to improve the mechanical structure of particular soil prior to soil engineering works. The re-utilization of industrial wastes is widely used in stabilization of problematic soils. Therefore, this study aimed to establish the effect of rice husk ash (RHA) addition on the geotechnical characteristics of treated residual soil. The treated samples were prepared by mixing varying amount of RHA between 0% and 20% of the base soil. The results found that the Atterberg limits of liquid limit, $w_L$ and plastic limit, $w_p$ decreased as the amounts of added RHA were increased. Compaction tests indicated an increase in maximum dry density, $\rho_{max}$ and decrease in optimum water content, $w_{opt}$ with the increase of RHA contents. As RHA contents were increased in treated soils, the hydraulic conductivity and soil strength values also increased apparently. These results showed that the presence RHA can modify the geotechnical characteristics of treated residual soil and can be potentially utilized as alternative material for soil stabilization.

Key words: Residual soil • Rice husk ash (RHA) • Geotechnical characteristics • Shear strength

INTRODUCTION

Residual soil is the largest earth material that engineers dealt with especially in tropic environments [1]. It is developed directly by physical and chemical weathering of the underlying parent rocks. According to Taha et al. [2] and Amiaton et al. [3], more than 75% of Peninsular Malaysia is mantled by residual soil. Therefore, this soil has been widely used as a medium for foundations or material for constructions. However, its strength is relatively low attributed to the weakly bonded structures inherited from parent rock or secondary crystallization during weathering process [4, 5]. Prior to construction, soil improvement will be performed to enhance its mechanical behaviors to suit with the construction requirements. Soil improvement can be either by modification, stabilization or both [6]. Soil modification involves addition of modifier into soil to modify its index properties while soil stabilization is to enhance strength and durability of soil that suit for construction.

In common practice, improvement of soil using conventional additive materials such as cement and lime that has kept the cost of construction financially high [7]. The price of these materials has dramatically increased due to highly demand and sharp increase in the cost of energy since 1970s [6, 8]. Industrial wastes can be introduced as potential materials for soil improvement. The wastes can be recycled as additive materials in soil hence, contribute to improvement of its mechanical properties and the fact that reusing of these materials keeps them from being dumped into landfills [9]. According to DOE [10, 11] the amount of wastes in Malaysia are increasing annually and most of them are under-utilized that need spaces to dispose safely. Re-utilization of wastes is an approach to minimize the over dependence on conventional materials and problems related to waste disposal management. In addition, it conserves the natural resources and saves the energy consumption at production stage.
Common additive materials used in soil stabilization are cement and lime. These conventional materials are not sustainable because of their total reliant on natural resources. Production of Portland cement is associated with green gas emissions that are implicated in global warming and climate change [12]. Thus, many studies have been conducted to examine the potential utilization of waste materials and its effect on geotechnical behaviors [13-17]. The alum-treated waste water sludge has been studied for its potential additive ingredients in production of cement and soil amendment purposes [18, 19]. Bernd and Carl [20] studied the potential utilization of sewage sludge ashes as secondary raw materials in construction sector. Several studies showed that industrial wastes can be utilized as additive materials for soil improvement [21-23].

Rice husk is among agricultural residue that generated from the rice milling plants and burning is a common practice applied in disposing of the rice husk. It is estimated that approximately 22 million tonnes of ash was produced annually [24]. The abundant available of rice husk has created environmental problem related to burning activity. It consists of silica (SiO$_2$), aluminium oxide and iron oxide, compounds that attribute to pozzolanic reaction. Several attempts have been performed to produce pozzolanic material from rice husk that can be utilized for strength improvement [25-27]. Pozzolanic activity of pozzolanic material such as RHA is influenced by the content of amorphous SiO$_2$ and its fineness. A better quality of RHA can be yielded by controlling the burning temperature and environment [24, 28]. Chopra et al. [29] found that silica (SiO$_2$) is in amorphous form when RHA is fired at temperature of 700°C. Ramadhansyah et al. [30] also prepared RHA sample which was heated at 700°C in order to study the thermal effect on grinding time of RHA.

Application of RHA as additive material has been extensively studied for partial replacement of cement in concrete mixture [31,32]. It has also been studied for remediation of contaminated water and a raw material for absorption of acid dyes in textile effluents [33-35]. Attempts have been made to use RHA in modifying the geotechnical properties of soil for stabilization of problematic soils [36, 37]. The influence of RHA on the compaction behavior of black cotton soil was examined by Yadu et al. [38]. Basha et al. [39] found that the addition of rice husk ash responsible in reducing the plastic limit and maximum dry density of soils. Combined application of RHA and lime can modify the expansive soil by reducing the swelling index and improve its strength and bearing capacity [40].

This study examined the potential of rice husk ash (RHA) as an additive material for stabilization of the studied residual soil. A direct application of RHA was adopted in this study therefore least energy usage could be imposed during preparation of treated soil samples. The basic characteristics of base soil used in this study were determined. The effects of the RHA on the geotechnical characteristics of residual soil were assessed in terms of consistency index, compaction, permeability and strength.

**MATERIALS AND METHODS**

**Materials Used and Preparation of Treated Sample:**

The base soil used in this study was residual soil originated from in-situ weathering of granitic rock. Soil samplings were carried out in Hulu Langat, Selangor as shown in Fig. 1. Undisturbed samples were collected at 0.3 meter depth of open trench using metal core sampler. Core sampler was pushed into soil and was carefully taken out in order to minimize disturbance to the peat soil sample. Both openings were sealed with paraffin wax to preserve its moisture content. Then the sample was wrapped with plastic film, labeled and stored in plastic storage. A bulk sample approximately 50kg of soil was collected using hand shovel and stored in a plastic container which later would be used for laboratory testing and sample preparation.

The undisturbed soil samples were used to determine the value of their field undrained shear strength and natural moisture content. Shear strength coefficient was determined from the unconsolidated undrained or simply known as quick test. Meanwhile for the bulk samples, the soils were openly air-dried under room temperature condition for a week. Any soil aggregate was gently crushed by hand and mortar to individual grain. Then the samples were sieved to pass through 2 mm sieve size. These samples were used to determine the basic characteristics of untreated soil and to prepare treated soil for their geotechnical characterization.

The soil is characterised by reddish-brown to orange brown colour as shown in Fig. 1b. Close observation of hand sample clearly indicated the presence of apparent quartz grains that is inherited from its parent rock (Fig. 1b). The basic characteristic of base soil used in this study is illustrated in Table 1. The particle size distribution analysis of the base soil indicated that sand fraction was the highest if compared to clay and silt fractions. The soil is classified as silty sand or SM and is acidic with pH of 4.2 (Table 1). The obtained pH for the studied soil is within the range values that were recorded...
Fig. 1: (a) Map of sampling location for base soil and (b) site view of soil exposure.

Table 1: Summary of basic characteristics of base soil of residual soil and RHA.

<table>
<thead>
<tr>
<th>Property</th>
<th>Base Soil</th>
<th>RHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.24*</td>
<td>10.4*</td>
</tr>
<tr>
<td>Organic content (%)</td>
<td>-</td>
<td>5.1</td>
</tr>
<tr>
<td>Natural moisture content, w (%)</td>
<td>23.9*</td>
<td>-</td>
</tr>
<tr>
<td>Specific gravity, G</td>
<td>2.54*</td>
<td>2.08*</td>
</tr>
<tr>
<td>Particle size distribution (%)</td>
<td>53.7</td>
<td>-</td>
</tr>
<tr>
<td>Sand</td>
<td>53.7</td>
<td>-</td>
</tr>
<tr>
<td>Silt</td>
<td>24.4</td>
<td>-</td>
</tr>
<tr>
<td>Clay</td>
<td>21.9</td>
<td>-</td>
</tr>
<tr>
<td>XRD analysis</td>
<td>Quartz, kaolinite, muscovite, illite</td>
<td>-</td>
</tr>
</tbody>
</table>

* Mean value.

Table 2: Chemical composition of RHA in comparison with RHA produced in Malaysia (Abu Bakar et al., 2009).

<table>
<thead>
<tr>
<th>Composition</th>
<th>Malaysia</th>
<th>Brazil</th>
<th>Netherlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>93.1</td>
<td>92.9</td>
<td>86.9</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.21</td>
<td>0.18</td>
<td>0.84</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.21</td>
<td>0.43</td>
<td>0.73</td>
</tr>
<tr>
<td>CaO</td>
<td>0.41</td>
<td>1.03</td>
<td>1.4</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.31</td>
<td>0.72</td>
<td>2.46</td>
</tr>
<tr>
<td>MgO</td>
<td>1.59</td>
<td>0.35</td>
<td>0.57</td>
</tr>
<tr>
<td>Na₂O</td>
<td>*</td>
<td>0.02</td>
<td>0.11</td>
</tr>
<tr>
<td>SO₃</td>
<td>*</td>
<td>0.1</td>
<td>*</td>
</tr>
<tr>
<td>LOI</td>
<td>2.36</td>
<td>*</td>
<td>5.14</td>
</tr>
</tbody>
</table>

* not specified

The rice husk ash (RHA) sample was collected from LPN Mill which is located in Tanjung Karang, Selangor. Field observation showed that RHA is characterized by black colour as a result of the burning of the rice husk in open environment. This is a common practise of mill operators to dispose the rice husk before being transport to the landfill. RHA showed moderately alkaline with pH value of 10.4. Its specific gravity is lower if compared to the base soil. Table 2 shows a comparison of chemical composition of RHA from different countries as reported by Abu Bakar et al. [28]. The difference in chemical composition was reflected by the several factors such as soil chemistry, varieties in paddy, weather and fertilizer [46, 47]. SEM images of RHA and soil with RHA mixture are shown in Fig. 2. RHA composed elongated hollow particles that represented the residue of rice husk after burning process.

Preparation of the treated soil samples was prepared by mixing base soil of granitic residual soil with rice husk ash (RHA) at percentages between 0% and 20% of dried weight of peat soil. The RHA treated samples were prepared for geotechnical characterization such as the determination of Atterberg limit, compaction behaviour, permeability and soil strength. In order to homogenize the initial condition of RHA collected from site, the sample
Fig. 2: SEM images of RHA and soil-RHA mixture

was oven-dried for 24 hours prior to preparation of the RHA treated soil. In this study, the preparation of RHA was kept to minimum as possible in order to use RHA straight away without firing up to high temperature and no grinding was performed. Therefore, the physical nature of its hollow elongated structure would be preserved. Preparation of treated samples for permeability and soil strength tests were carried out in compaction mould. Samples for shear strength test extruded from the compaction mould and dried at room temperature for curing. The core samples prepared were 38 mm in diameter with height of 80 mm. For permeability tests, samples had been prepared in compaction mould were then set up in falling head permeameter apparatus after curing stage completed. All the RHA treated soil samples were cured for three days before being set up in experimental apparatus for geotechnical testing.

**Experimental Procedures for Treated Soil:** The treated soils were examined for their consistency index (Atterberg limit), compaction, permeability and strength. A total of four sets of RHA treated samples were prepared and each set consisted of added RHA contents between 0 and 20% of dry weight of dried base soil.

Determination of the consistency index of Atterberg limit consists of liquid limit and plastic limit. The Casagrande cup technique was applied to determine the liquid limit, \( w_L \) of soil [48]. Sample was placed in metal Casagrande cup and 13 mm wide channel was halved the sample using a special tool. Then the cup was dropped repeatedly until the gap closes and numbers of drop were recorded. The representative samples were then collected to determine the moisture content at liquid limit. The liquid limit value is equivalent to 25 blows or drops. Plastic limit, \( w_P \) of the soils was estimated by rolling the soil thread into 3 mm in diameter without crumbling. The moisture content of the representative sample was also determined (\( w_p \)). The difference between the liquid limit and plastic limit is defined as plasticity index, \( I_p \).

A standard Proctor 2.5 kg of compaction effort (also known BS light) was applied to determine the compaction behavior of treated soil samples. This technique was performed based on the procedure suggested by BS 1377 [49]. Compaction test requires approximately 2.5 kg of soil sample for each test. Soil sample was placed in metal mould and compacted with 2.5kg rammer, dropped from the controlled height of 300 mm from the surface of soil. On each layer, twenty seven blows were applied evenly on each layer. A second layer soil was added and compacted with 27 blows up to three uniform layers. Representative samples were collected to determine the moisture content. Repeat a similar procedure for samples with an increment of water added up to five compactions. Compaction curve was delineated to establish the values of maximum dry density, \( \rho_{max} \) and optimum moisture content, \( w_{opt} \) for each RHA treated soil with different contents.

Permeability tests were conducted on RHA treated samples based on the technique suggested by BS 1377 [50]. Soil samples were prepared in a standard compaction test mould prior to setting up in permeameter apparatus. After curing stage was completed, the samples were transferred to falling head permeameter. The samples were then initially saturated before permeability can be initiated. At least five readings were taken from each test of RHA content in order to calculate the mean value. Meanwhile, the strength of treated soils was determined with unconsolidated undrained triaxial tests (UU tests) to estimate soil strength in terms of total stress (not effective stress). This test is straightforward test and known as quick tests [51]. For each test of RHA content, three set of core samples were prepared in compaction mould at
maximum dry density, $\rho_{\text{max}}$ and optimum moisture content, $w_{\text{opt}}$. Each core sample has dimension of 38 mm diameter and 76 mm high. Soil samples were subjected to different confining stresses of 140, 280 and 420 kPa imposed by cell pressure, $\sigma_c$, prior to shearing. Shearing of samples performed at constant strain rate of 1.00 mm min$^{-1}$ and continued until the soil failed or up 20% of axial strain.

RESULTS AND DISCUSSION

Soil Consistency Index: Soil consistency index examined was Atterberg limit and widely used to discriminate between different soil types and states [52]. The Atterberg limit of liquid limit, $w_L$ and plastic limit, $w_p$ of treated soils were determined in order to examine the influence of RHA contents used in treated soil. Fig. 3 presents the results of the liquid limit, plastic limit and the plasticity index, $I_p$. It was clearly indicated that the values of $w_L$ and $w_p$ decreased with the increasing proportion of RHA. The values of plasticity index, $I_p$ similarly showed a reduction trend from 37% to 27% when RHA content increased up to 20%. The trend of decreasing in Atterberg limit values was apparently occurred at 5% of RHA content from 74% to 61% for liquid limit, $w_L$ while 41% to 34% for plastic limit, $w_p$. It was shown that a further increase in RHA contents beyond this value (5%), the decrease in values of $w_L$ and $w_p$ were generally small. The drop in the values of $w_L$ and $w_p$ with increasing amounts of added RHA was also reported by other researchers such as Basha et al. [39], Agbede and Joel [53] and Yadu et al. [40]. It is well acknowledged that the presence of clay content and mineralogy controls the liquid and plastic limits of particular soil [54]. Therefore the reductions in liquid and plastic limits are attributed to the replacement of soil fines by the presence of RHA in treated soil [37]. As RHA contents were increased, the ratio of soil-RHA was decreased and amount of water required would be less. Beyond 5% of RHA content, amounts of required water for both limits were slightly changed as shown by the tests. It can be generally stated that 5% of RHA is the optimum amount to reduce the plasticity of the studied soil. As comparison, Basha et al. [39] found that the optimum content of RHA added to granitic residual soil was between 10 and 15%. A reduction in $I_p$ indicates an improvement to the treated soil.

The results of $I_p$ and $w_L$ from Atterberg limit tests were plotted on Casagrande plasticity chart. This chart illustrates the changing in the plasticity of soil as well the particle size of soil fines (Fig. 4). From the chart, all the untreated and treated soil samples distributed well below the A-line. With further increases in RHA content in treated soils, the untreated soil that initially was silt with very high plasticity shifted to silt with moderately plasticity. It is clearly seen that the plots moved close to the A-line suggesting that the soil class turn slightly toward clay size characteristic.

Compaction Characteristics: Compaction is an effort to increase the density of soil mass by bringing down the voids with increasing soil water content [55]. At particular water content, the density of soil is at maximum value and the corresponded water content is known as optimum water content. Subsequent amount of water added will result with reduction of soil density.

The results of the compaction tests on untreated and RHA treated soils are shown in Table 3 while the compaction curves are shown in Fig. 5. The maximum dry

![Fig. 3: Effect of RHA content on Atterberg limits values.](image)

![Fig. 4: Plasticity chart for the RHA treated soils.](image)

<table>
<thead>
<tr>
<th>RHA content, %</th>
<th>$\rho_{\text{max}}$, g/cm$^3$</th>
<th>$w_{\text{opt}}$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.73</td>
<td>17.8</td>
</tr>
<tr>
<td>5</td>
<td>1.69</td>
<td>18.3</td>
</tr>
<tr>
<td>10</td>
<td>1.63</td>
<td>19.7</td>
</tr>
<tr>
<td>20</td>
<td>1.52</td>
<td>22.4</td>
</tr>
</tbody>
</table>
Permeability:
Permeability of RHA treated soils was performed in order to examine the influence of RHA on the studied soil. Therefore, a series of falling permeability tests on untreated and treated soils were carried out and the results of the tests are shown in Fig 6. Based on the results, permeability of the treated soil increased with the increase in the amount of RHA content.

The increase in permeability value ranged from 5.66 × 10^{-5} m/sec for untreated soil up to 5.87 × 10^{-5} m/sec for treated soil with 20% RHA content. The change in permeability value in treated soil is attributed to the nature of RHA that enhance the absorption of water. SEM observation found that RHA particles are characterized by hollow cellular and porous structures (Fig. 2a). Therefore, by increasing the RHA content, the permeability of soil was also increased due to the replacement of smaller inter-particle space of soil by more porous material of RHA. Kartini et al. [58] also reported a similar trend in permeability of RHA blended in concrete material. It was reported earlier by Alhassan [7] that the permeability of RHA treated soil can be brought down by integrating lime with RHA. This phenomenon was as a result of pozzolanic reaction between calcium in lime compound with available silica and/or alumina from soil and RHA would create a cementitious compound that filling inter-particle spaces subsequently hindering the flow of water.

Shear Strength:
The effect of RHA treatment on shear strength was examined by using the unconsolidated undrained triaxial tests. All samples were subjected to confining stresses of 140, 280 and 520 kPa prior to shearing. Fig. 7 show the stress-strain curves of the triaxial tests for untreated RHA treated soils at three different applied confining stresses. The plot of the undrained shear strength coefficient, $C_s$, of treated soil against the different amount of added RHA is shown in Fig. 8.

Based on the shear-strain curves for each confining stress, the deviatoric stress, $q$, was linearly increased at early axial strains, $e_a$, up to 5% (Fig. 7). Most of the treated samples indicated higher axial strain of linear increment in $q$ in compared to that of untreated soil (0% RHA). For untreated soil, the linearity trend of $q$ diminished earlier, $e_a$, approximately less than 2%. It was apparently observed
that samples treated with RHA tend to behave like a brittle material which indicated by significant peak due to shear plane failure while untreated samples associated with ductile mode of failure [4]. As the added RHA contents were increased, the peak of deviatoric stress, $q$ became more significant as seen in samples treated with 20% RHA (Fig. 7).

The effect of RHA content on the shear strength, $C_s$, is clearly shown in Fig 8. The plot showed that the value of $C_s$ was increased as the amount of added RHA increased. At 5% of added RHA, the increase in $C_s$ was slightly higher than the untreated soil. However, further amount of RHA contents from 5% to 10% and 20% indicated further increase in $C_s$ from 168 kPa to 313 kPa and 405 kPa, respectively representing 121% and 185% increases from the actual strength of untreated soil. A similar behaviour was reported by earlier studies in agreement with the increase in strength of RHA treated soil [39, 52, 59, 60]. As stated earlier, the improvement of strength with added RHA is due to the pozzolanic reaction. Sarkar et al. [52] found that agglomeration in large size particles occurred in treated soil as a result of pozzolanic activity which attributed to improvement in compressive strength. This agglomeration in treated soil has changed the soil texture from clay to silt texture. Bash et al. [39] reported that the RHA-soil mixture showed slightly increase in strength because the lack of cementitious properties in RHA. By adding RHA to cement-soil mixture can significantly improve the strength of treated soil, subsequently can reduce the amount of cement used soil stabilization.

### CONCLUSIONS

Several conclusions can be outlined based on the results obtained from a series of testing of untreated and RHA treated soils.

- Addition of RHA can decreases the plasticity of residual soil and shifted the high plasticity silt to moderately plasticity silt. It seemed that treated soils moved closer to the A-line of Casagrande’s plasticity chart.
- The presence of RHA used to treat residual soil has decreased the value of maximum dry density, $\rho_{dmax}$ whilst the optimum moisture content, $w_{opt}$ has been elevated as more RHA content is being used in soil mixture.
- The permeability of RHA treated soil showed a reduction with the increase in added RHA content due to the nature of RHA used in this study. As seen under SEM, the nature of physical structure of RHA was preserved and this attributed to the increase in permeability of RHA treated soil.
- RHA can be used to improve the shear strength of residual soil as indicated by significant increase in shear strength coefficient with the increase in RHA content. The application of RHA as an additive material in soil stabilization will benefit to the economic in general as alternate material will partially replace the conventional cement in construction sector.
ACKNOWLEDGEMENTS

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