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Stabilization of residual soil with rice husk ash and cement

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Abstract

Stabilization of residual soils is studied by chemically using cement and rice husk ash. Investigation includes the evaluation of such properties of the soil as compaction, strength, and X-ray diffraction. Test results show that both cement and rice husk ash reduce the plasticity of soils. In term of compactability, addition of rice husk ash and cement decreases the maximum dry density and increases the optimum moisture content. From the viewpoint of plasticity, compaction and strength characteristics, and economy, addition of 6–8% cement and 10–15% rice husk ash is recommended as an optimum amount.

Keywords: Chemical stabilization; Cement; Rice husk ash; Residual soil

1. Introduction

Stabilized soil is, in general, a composite material that results from combination and optimization of properties in individual constituent materials. Well-established techniques of soil stabilization are often used to obtain geotechnical materials improved through the addition into soil of such cementing agents as Portland cement, lime, asphalt, etc. Replacement of natural soils, aggregates, and cement with solid industrial by-product is highly desirable. In some cases, a by-product is inferior to traditional earthen materials. Due to its lower cost, however, it makes an attractive alternative if adequate performance can be obtained. In other cases, a by-product may have attributes superior to those of traditional earthen materials. Often selected materials are added to industrial by-products to generate a material with well-controlled and superior properties.

Investigators such as Gidley and Sack [1] proposed several methods for utilizing some industrial wastes in engineering construction. Other studies examined the possibility of improving soil properties such as increasing shear strength, reducing settlement, and minimizing swelling problems by using solid waste. Kamon and Nontananandh [2] combined industrial waste with lime to stabilize soil. Attom and Al-Sharif [3] evaluated burned olive waste for use as soil stabilizer, which is a partial solution to the problems associated with the increase of olive waste in Jordan.

For a given country, in the application of principles of soil stabilization developed elsewhere, an understanding of local conditions is of paramount importance [4]. The soil found locally, in a place, may differ in imperative aspects from soils tested in others. Soil type and climatic conditions affect the characteristics of stabilized soil materials as well as technical method and procedures. The rate of curing may proceed rapidly at higher temperature [5] and rain may affect the compaction and strength of stabilized soil. Residual soils are typical materials of the rural areas in Malaysia, e.g. applied to road and embankment construction. The residual soils in their natural state are suitable for subbase at least, but not for the standard pavement base material [6].

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In the agricultural countries, there are problems with abundance of agriculture wastes. Those plants obtain various minerals and silicates from earth in their bodies during growth process. Inorganic materials, especially silicates, are found in higher proportions in annually grown plants than in the long-lived trees. Rice, wheat, sunflower, and tobacco plants therefore contain higher amounts of silica in their cuticle parts. Inorganic materials are found in the forms of free salts and particles of cationic groups combined with the anionic groups of the fibres into the plants [7]. The result of burning organic materials is called thermal decomposition. The ash produced in this way is ground to a fine size and mixed with lime in order to obtain a material with a binding characteristic. The quality of this material depends on burning time, temperature, cooling time, and grinding conditions [8,9]. The primary objective of this study is to examine the potential of burnt agricultural by-product, rice husk, as a material for stabilising soil. The effects on the consistency, density, and strength of residual soil are studied.

Table 1
Properties of the residual soil

Properties	Value
Physical properties	
Natural water content	26%
Liquid limit	36.77%
Plastic limit	22.95%
Plasticity index	13.82%
Linear shrinkage	6.71%
Specific gravity	2.37
Particles	
Sand	46%
Silt	44%
Clay	10%
Chemical	
Silica (SiO_2)	71.16%
Alumina (Al_2O_3)	16.15%
Iron oxide (Fe_2O_3)	4.98%
Potash (K_2O)	1.46%
Magnesia (MgO)	0.25%
Loss on ignition	5.61%

2. Experimental investigation

2.1. Materials used

2.1.1. Soils

Residual granite soil, which is a typical residual soil in Malaysia, is used in this study. Table 1 presents the properties of the soil, while Fig. 1 shows the diffractograph of the residual soil. Kaolinite clay mineral is identified in the residual soil by a strong diffraction line at 3.57 Å, which disappeared when the clay is heated up to 550 °C.

2.1.2. Rice husk ash

Rice husk was considered as valueless by-product of rice milling. At the mills, disposal of the hulls is achieved by burning them in heaps near the mills. Even though, the ashes have been potential pozzolanic materials suitable for use in lime–pozzolana mixes and for portland cements replacement [10]. The ashes used in this study

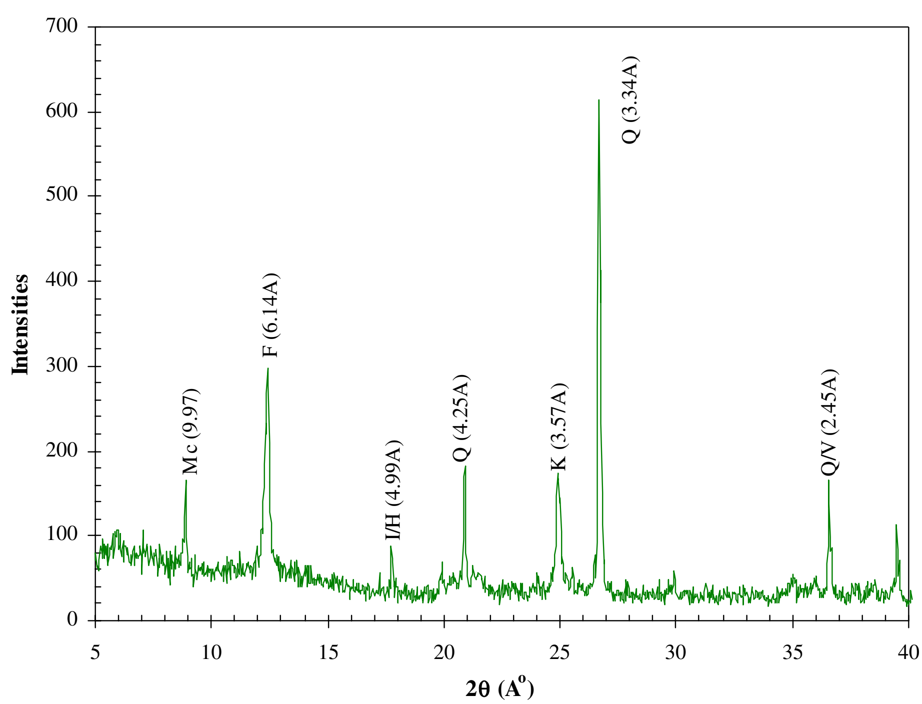

Fig. 1. X-ray diffractograph of residual soil. F, Feldspar; Mc, Muscovite; K, Kaolinite; Q, Quartz; I, Illite; H, Halloysite; V, Vermiculite.

are obtained from burning of rice husk in the incinerator. The properties of the ashes are tabulated in Table 2.

2.1.3. Cement

The cement used is ordinary portland cement. The physical and chemical properties of the cement are given in Table 2.

2.2. Laboratory tests

2.2.1. Atterberg limits tests

The Atterberg consistency limits were determined in accordance with the British Standard methods – BS 1377: Part 2 [11]. The residual soil was sieved through 425 mm. Materials that retained on that sieve were rejected for this test. The soils, then, were oven-dried for at least 2 h before the test. The tests were carried out on the soils with different proportion of cement and rice husk ash (RHA).

2.2.2. Compaction tests

Proctor standard compaction test, according to BS 1377–1990: Part 4 [11] was applied to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. The soil mixtures, with and without additives, were thoroughly mixed with various moisture contents and allowed to equilibrate for 24 h prior to compaction. The first series of compaction tests were aimed at determining the compaction properties of the unstabilized soils. Secondly, tests were carried out to determine the proctor compaction properties of the clay upon stabilization with varying amounts of cement and RHA.

Table 2
Physical and chemical properties of the cement and RHA

Properties	Cement	RHA
Physical properties		
Moisture content		
Specific gravity		3.68%
Fineness	3.12	2.08
	2975 cm^2/g	12.5%
		(Retained 45 μm sieving)
Chemical composition		
Silica (SiO_2)	20.44%	93.15%
Alumina (Al_2O_3)	5.50%	0.21%
Iron oxide (Fe_2O_3)		0.21%
Calcium oxide (CaO)	64.86%	0.41%
Potash (K_2O)		22.31%
Magnesia (MgO)	1.59%	0.45%
Loss on ignition	1.51%	2.36%
pH	12.06	9.83
3CaO · SiO2	66.48%	
2CaO · SiO2	10.12%	
3CaO · Al2O3	8.06%	
4CaO · Al2O3 · Fe2O3	9.43%	
Free lime	1.65%	

2.2.3. Unconfined compressive strength and durability tests

Each specimens used in unconfined compressive tests were statically compacted in a cylindrical mould, 50 mm in diameter by 100-mm height, at OMC and MDD. The test was conducted according to BS 1924: Part 2 – Section 4 [12]. Specimens were, after moulded, cured in plastic bag for 7 days to prevent the moisture due to change. A series of specimens were soaked under water for 7 days to simulate the effect of heavy rain on the strength.

2.2.4. California bearing ratio test

At this stage, a portion of 6 kg materials was prepared at the OMC and compacted using a 2.5-kg mechanical rammer. The specimens were compacted in the three layers under 62 blows of rammer for each. After 7 days of moist-curing, the specimen was then soaked for 7 days in water and the other specimen continued to cured until its old was 14 days. From the test results, an arbitrary coefficient CBR was calculated. This was done by expressing the forces on the plunger for a given penetration, 2.5 and 5 mm, as a percentage of the standard force. This method has been already described in BS 1377–1990: Part 4.

3. Results and discussion

3.1. Effect on the consistency limits

The effect of cement and RHA stabilized soils on the liquid limit (LL) and plasticity index (PI) on the different soils are shown in Fig. 2. In this context, it is illustrated that reduce in plasticity of cement/RHA stabilized-residual soils as a result of increase in LLs and plastics limits.

It can be observed that cement and RHA reduce the plasticity of soils. In general, 6–8% of cement and 10–15% RHA show the optimum amount to reduce the plasticity of soil. Reduce in the PI indicate an improvement.

3.2. Effect on the compactability

Fig. 3 shows the effect of the addition of cement, RHA, and cement–RHA mixtures on the compaction characteristics of the soils tested. The figure depicts that adding cement and RHA increased the OMC and diminish amount of the MDD correspond to increasing of cement and RHA percentage. The increase in OMC is probably a consequence of two reasons: (1) the additional water held with the flocculant soil structure resulting from cement interaction, and (2) exceeding water absorption by RHA as a result of its porous properties, as reported in Zhang et al. [13]. Principally, increase in dry density is an indicator

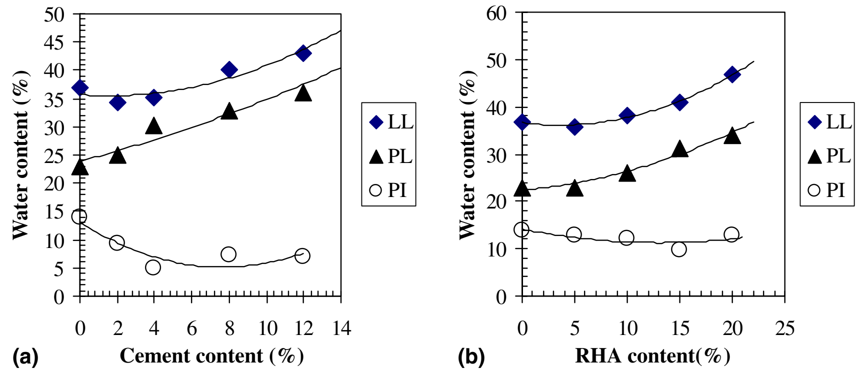

Fig. 2. Variation of consistency limits: (a) cement-stabilized residual soil; (b) RHA-stabilized residual soil.

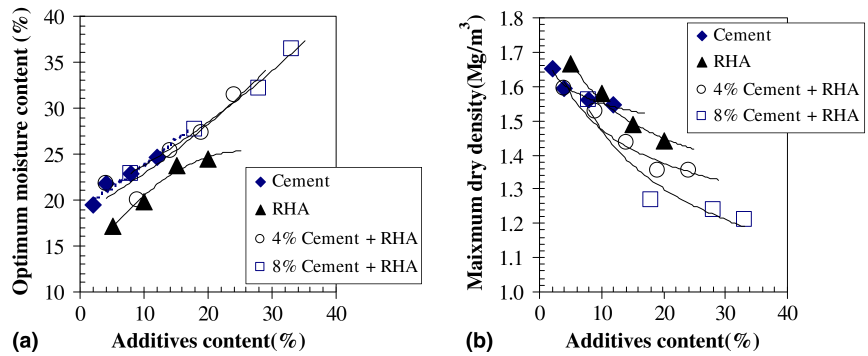

Fig. 3. Variation of compaction characteristics: (a) optimum moisture content; (b) maximum dry density.

of improvement. But, unfortunately, both cement and RHA, instead, reduce the dry density. Rahman [14] reveals an opinion that the change-down in dry density occurs because of both the particles size and specific gravity of the soil and stabilizer. Decreasing dry density indicates that it need low compactive energy (CE) to attain its MDD. As a result, the cost of compaction becomes economical [15].

3.3. Effect on the compressive strength

The effect of the addition RHA and cement on the unconfined compressive strength is shown in Fig. 4. Cement shows undoubtedly a very effective additive to enhance the strength of tested soils. In Fig. 4, it can be observed that the optimum cement content is 8%. It corresponds with the optimum cement content that reaches to the consistency limit. In contrast with RHA–soil mixtures, the RHA slightly increases the strength because of the lack of cementitious properties in RHA as presented in Table 2. In agreement with Hossain [16], hence, RHA cannot be used solely for stabilization of soil. This investigation shows that cement-stabilized soils can be intensified by adding between 15–20% of RHA as shown in Fig. 4. The figure either shows that 4% cement mixed with residual soil and 20% RHA, kaolin with 4% cement and 15% RHA, and bentonite with 4% cement and 15% RHA have a strength, respectively, almost 4, 2, and 1.4 times that of a sample with 8% cement. A lesser amount of cement is required to achieve a given strength as compared to cement-stabilized soils. Since cement is more costly than RHA this results in lower construction cost.

3.4. Durability of stabilized residual soil

Resistance to immersion in the unconfined strength of 4% cement–RHA–residual soil mixtures is summa-

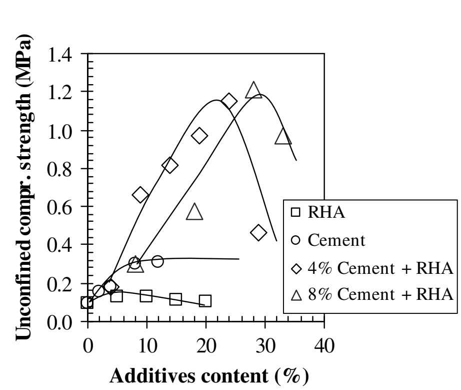

Fig. 4. Effect of the addition of RHA and cement of unconfined compressive strength.

Table 3
Resistance to immersion in the unconfined strength of 4% cement–RHA–residual soil mixtures at OMC + 3% water content

4% Cement + RHA (%)	Unsoaked (MPa)	Soaked (MPa)	Ratio (soaked/unsoaked)
0	0.993	0.882	0.89
5	2.203	1.654	0.75
10	3.305	3.151	0.95
15	3.72	3.309	0.89
20	3.646	3.011	0.83
25	3.299	1.873	0.57

rized in Table 3. A stabilized soil should have the resistance of its integrity and services – strength along the lifetime of construction. This experiment exhibits that the addition of RHA in cement-residual soil mixtures has better resistance subject to 7 days immersion. It can be seen that the strength of residual soil mixed with 4% cement and five different RHA content decreased up to 89%, 75%, 95%, 89%, 83%, and 57%, respectively, for 0%, 5%, 10%, 15%, 20%, and 25% RHA. Mixes of 5%, 20% and 25% RHA with 4% cement have greater reduction of strength than cement only. But, the strength raised is still higher than cement stabilized residual soil.

3.5. Effect on California bearing ratio

The laboratory determination of the CBR of a compacted specimen was obtained by measuring the forces

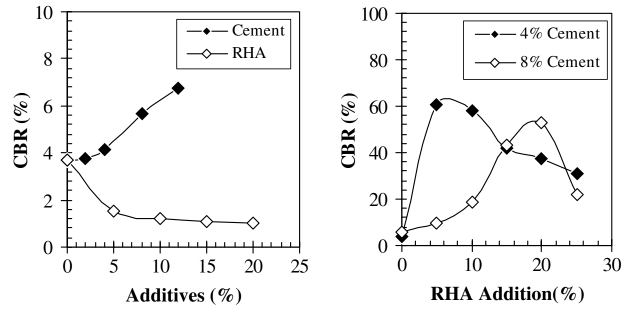

Fig. 5. Effect of cement and RHA addition on CBR.

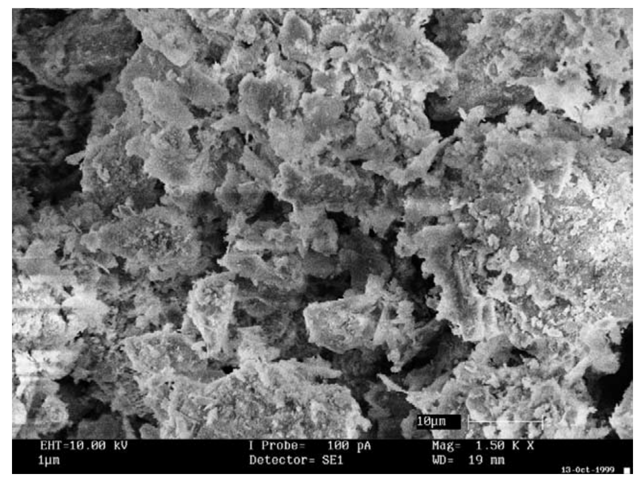

Fig. 6. Scanning electron microscograph of stabilized soil with 4% cement and 20% RHA.

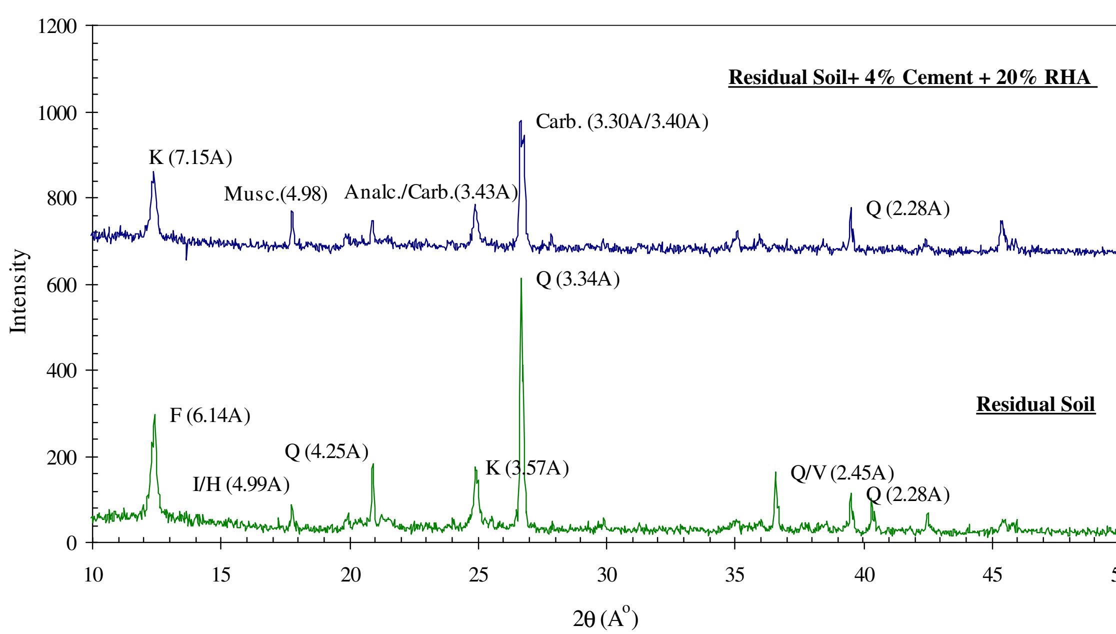

Fig. 7. X-ray diffractograph of stabilized soil after 7 days moist-curing. F, Feldspar; Mc, Muscovite; K, Kaolinite; Q, Quartz; I, Illite; H, Halloysite; V, Vermiculite; Analc., Analcite; Carb., Carbonate.

required to cause a cylindrical plunger of a specified size to penetrate the specimen at specified rate. As with the unconfined compressive strength, the CBR increases with addition of lime (Fig. 5(a), but, however, the RHA-treated residual soils decrease the CBR value. This, again, alludes that RHA alone is not suitable as stabilizer. Combination between RHA and cement yields a significant enhancing of strength as well as CBR (Fig. 5(b)). This result confirms that 4% cement–5% RHA mixtures, and 8% cement–20% RHA mixtures attain the maximum CBR value, respectively, 60% and 53%. Multiple enhancement of CBR value is reached when lesser cement content and RHA is mixed. Further, this is an benefit for road construction.

3.6. X-ray diffraction and SEM

The effect of addition of additives on the soil structure has been observed by SEM and X-ray diffraction test as figured in Figs. 6 and 7 respectively. This figure explains that the new structure soil has been appeared in soil stabilized with 4% cement and 20% RHA.

Presence of the analcite and carbonate at peak 3.43 and 3.30 Å exhibits a reaction processed. This implies that pozzolanic reaction is taking a place to form a cementitious material. The peak of quartz (3.34 Å) and feldspar (6.14 Å) has been disappeared at stabilized residual soil.

4. Conclusions

The following conclusions can be drawn on the basis of test results obtained from cement–RHA stabilized soils.

1. Cement and RHA reduce the plasticity of residual soil. A considerable reducing is attained by cement-stabilized soils.
2. The MDD of cement-stabilized residual soil slightly decreases with the increase in cement content. Adding RHA and cement, the OMC is increased steeply.
3. The unconfined compressive strengths of cement-stabilized soils increase with addition of RHA. Addition of RHA needs a lesser amount of cement to achieve a given strength as compared to cement-stabilized soils. The resistance to immersion shows a better improvement. Since cement is more costly than RHA this can result in lower construction cost.
4. The increase in CBR value corresponds to the increase in cement content. Adding RHA into cement-treated residual soil, the CBR value increase multiply. The maximum CBR, as much as 60% is found at combination of 4% cement and 5% RHA.
5. In general, 6–8% of cement and 15–20% RHA show the optimum amount to improve the properties of soils. Reduce in PI and increase in strength and resistance to immersion indicate an improvement.
6. RHA can potentially stabilize the residual soil, either solely or mixed with cement. Utilizing is an alternative, it is available to reduce construction cost, particularly in the rural area of developing countries.

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