EVALUATION OF FLY ASH AND RICE HUSK ASH ON THE UNCONFINED COMPRESSIVE STRENGTH OF THE COMPACTED CEMENT TREATED LATERITIC SOIL

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Abstract

The unconfined compressive strength (UCS) and modulus of elasticity characteristics for stabilized soil are required in many geotechnical applications. This work aimed to investigate the potential of Fly ash (FA) and Rice Husk ash (RHA) as cement replacement in soil stabilization of the lateritic soil for materials used in pavement applications. The specimens were compacted under modified Proctor at optimum water content. The cement content was varied from 1 to 3%, the percentage of ash replacement was varied from 10 to 30%. A series of UCS tests are carried out after 28 days of curing. To investigate deformation response, the Local Deformation Transducer (LDT) and the Linear Variable Differential Transformer (LVDT) were used to measure the deformation of the specimens. By considering the UCS value, the amount of RHA at 10-30% replaced effectively to the 1-2% cement mixed lateritic soil without reducing the mixing strength. Satisfactory performance of FA was observed at only 1% cement mixture. The modulus measured by both the LVDT and LDT has linear relations with the strength. The empirical expressions for predicting the strength of cement and cement-ash treated are used to characterize the influences of mixing ratio on the strength of cement-ash treated lateritic soil. The efficiency factor and effective void ratio concepts are reasonable to predict the strength of cement-ash treated lateritic.

Keywords: **Lateritic, Stabilization, Fly ash, Rice Husk ash, Unconfined Compressive Strength**

Introduction

Currently, in Thailand, the rapidly growing road constructions are under construction or being planned, which has increased the demand for construction materials. The performance and service life of any road are mainly governed by the quality of pavement structure (Lekha *et al.*, 2015). Lateritic soils have been found in the humid tropical regions. The lateritic is mostly originated from igneous rocks, riched in secondary oxides of iron and aluminium, formed by the in-situ weathering. The lateritic is commonly used as the construction material in civil engineering (Sunil and Krishnappa,

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2012). According to their local availability, lateritic soils are often used as the layer in pavement structure, mainly in the base, sub-base, and subgrade layers of the road (Camapum de Carvalho *et al.*, 2015; Ampadu *et al.*, 2017; Etim *et al.*, 2021b). In Thailand, compacted lateritic is practically used in the sub-base layer. However, natural lateritic's poor engineering characteristics (i.e., high compressibility, high creep rate, low strength) are commonly found when it comes with a high amount of fine content (Attah *et al.*, 2021; Silva *et al.*, 2021).

From a geotechnical perspective, several approaches were utilized to modify or improve the engineering properties of lateritic soils. Traditionally, soil cement stabilization with chemical admixtures has been widely employed for improving the engineering properties of poor lateritic soils in many aspects (Mengue *et al.*, 2017; Etim *et al.*, 2021a). Technical literature provides evidence on beneficial of soil cement stabilization for instance, improving shear and compressive strength, reducing soil compressibility and permeability (Behnood, 2018).

The soil stabilizing agent or binders include a broad range of materials, for instance, Ordinary Portland cement, lime, and industrial by-product (Behnood, 2018; Sani *et al.*, 2019). Among these customary stabilizing agents, Portland cement and lime were widely used to stabilize the soil that did not meet the design specification (Etim *et al.*, 2020; Adetayo *et al.*, 2021). However, these stabilization agents own disadvantages: their extended cost and pollution in the production process (Jamnongwong *et al.*, 2018). In an offer to diminish a sharp addition in the cost, high silica and alumina material like pozzolanic material has taken instead some of cement in concrete works and assisted in reaction with hydroxide when it has high fineness (Jaturapitakkul and Jindaprasert, 2005; Moses *et al.*, 2019).

Hence, some attention is paid to investigating the possibility of using other cheap materials as a partial replacement (Etim *et al.*, 2020). For pavement applications, Odongo *et al*. (2019) examined the mechanical and physical properties of wood ash as a partial replacement of lime for stabilizing of lateritic soil. With 20%-40% of wood ash replacement, the blended material met the general specifications for National Roads of 2004, which was suitable for subgrade material. Research by Popoola *et al.* (2019) on locally available coconut waste ash on lime stabilized lateritic soil for road construction materials indicates that the unconfined compressive strength (UCS) and California bearing ratio (CBR) were significantly improved. The findings support the idea of using other low-cost or waste materials in road construction as a partial replacement of lime or Portland cement.

In order to utilize the pozzolanic materials as a cement replacement in cement stabilized soil, the influence of replacing pozzolan on the mechanical behaviors of the mixed material should be evaluated. For strength characteristics, it is well recognized that the unconfined compressive strength is suitable. The strength prediction with reasonable accuracy can help assess the mixing ratio and cost estimation, especially in the preliminary design state. The correlation between UCS and cement-water ratio (C/W) presented by Papadakis and Tsimas (2002) is widely used to evaluate the efficiency of ashes in concrete technology. Recent experimental studies conducted on deep mixing wet cement-treated clay have demonstrated that the engineering properties of cement-treated clay are influenced by many factors, including the mineral composition of clay soil, cement content, water content, and the curing time (Lorenzo and Bergado, 2004; Jongpradist *et al.*, 2010). Significant research has been conducted on the formulation of empirical expressions to predict the strength of cement and cement-ash treated soil (Horpibulsuk *et al.*, 2003; Lorenzo and Bergado, 2004; Jongpradist *et al.*, 2010, 2011). Most of them, the correlation measures of the strength were based on parameters governing strength characteristics, which includes the key parameters such as water content (C_w), cement content (A_w) and time and so on. Consoli *et al.* (2007), (2009) examined the effectiveness of the initial void ratio on mechanical properties of soil by assessing the USC of sandy soils stabilized by cement or lime. The concept of initial void ratio has been successfully employed in many different materials, such as cement-clay admixtures with high water content (Jongpradist *et al.*, 2011).

The current research presents a series of laboratory investigations on the feasibility of using fly ash and rice husk ash to replace ordinary Portland cement to improve the strength and stiffness properties of lateritic soil. The mixed materials were compacted, and a series of unconfined compressive strength tests were carried out by varying the cement content and ash replacement percentage. To investigate deformation response, by comparing and evaluating, the Local Deformation Transducer (LDT) and the Linear Variable Differential Transformer (LVDT) were used to measure the specimen deformation. Furthermore, from previous studies, the empirical expressions for predicting the strength of cement and cement- ash treated soil were used to characterize the influences of mixing ratio on the strength of cement-ash treated lateritic soil.

Materials and Methods

Lateritic Soil

The lateritic soil used for this investigation was taken from the open trial pit of depth 1-3 m below the ground surface of pit in Ratchaburi Province, Thailand. Ratchaburi situated about 60 miles west of Bangkok city area. Latitude and longitude coordinates are 13.528289 and 99.813423. The modified proctor test was utilized throughout the tests on crushed materials passed through a 9.8 mm sieve. The lateritic is reddish-brown. The specific gravity (G_s) was determined after oven-dried in the laboratory. The dry density, optimum moisture content (OMC), and natural moisture content were determined in the laboratory. The Atterberg limits are performed according to ASTM D-4318 (ASTM, 2000). The main physical properties obtained from preliminary classification tests are shown in Table 1.

Table 1. Engineering properties of lateritic soil in this study

Property	Quantity
Specific gravity	2.69
Percent passing #200 sieve (%)	22
Liquid limit (%)	19.29
Plastic index (%)	4.73
Classification AASHTO	A-2-4
Maximum dry density (kN/m^3)	20.6
Optimum moisture content (%)	9

Portland cement

The Portland cement type I from the (TPI) Polene Public Company Limited was used in the current study. The G_s of cement is 3.14.

Pozzolanic Materials

Two types of pozzolanic materials (fly ash and rice husk ash) were collected from different locations. The fly ash (FA) is the waste material from Mae Moh lignite-fired power plant, the northern part of Thailand. The fly ash was ground and sieved through a sieve number 325 with sieve opening 45 micrometers to obtain a fine ash that can be categorized as Class F. The rice husk ash (RHA) used in this study was the black rice husk ash. RHA was taken from Global Scales and Solution Company Limited, Nakorn Rachasima province. RHA was burnt at 400-800°C. The pozzolanic aggregates were broken down using the Los Angles Abrasion Machine and controlled to achieve a similar particle size distribution. The grain size distributions of all materials used are illustrated in Figure 1, and the chemical composition is listed in Table 2.

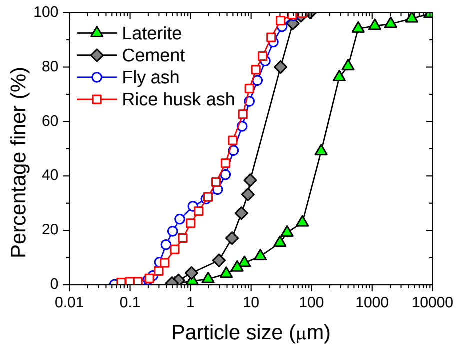

Figure 1. Grain size distribution of tested materials

Table 2. Chemical composition of Fly ash, Rice husk ash and Portland cement

Chemical Composition	Cement Type I	Rice Husk Ash	Fly Ash
SiO_2 (%)	20.20	92.99	48
Al_2O_3 (%)	5.40	0.17	26
Fe_2O_3 (%)	2.90	0.35	10
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	28.50	93.51	84
SO_3 (%)	2.30	0.11	0.7
CaO (%)	63.80	0.91	5
MgO (%)	1.50	0.42	2
Na_2O (%)	2.72	0.63	0-2
K_2O (%)	0.30	2.82	0-5
Other (%)	-	-	-
LOI. (%)	2	4.7	3

Sample preparation

After the lateritic soil agglomerates were completely dried in an oven at 50 degrees for three days, mixed lateritic and cementitious materials according to design mixing ratio until a homogenous mixture was obtained with water at amount of optimum moisture content. Then, the compaction tests were carried out following the standard of modified proctor method, ASTM D-1557 (ASTM, 2007) in accordance with the general standards and specifications for highways in Thailand. The compaction mold has inside diameter of 5 cm and 10 cm in height for 5 layers. Each layer is given the blows distributed uniformly over the surface of the sample according to the modified proctor effort (2,700 kJ/m3) to achieve the target unit weight at 20.6 kN/m^3. After compaction, the sample was removed from the mold, covered with a plastic wrap, and stored at room temperature (25°C) for 28 days. Figure 2 presents the overall view of the testing setup. After curing was completed, the specimen was placed on the lower platen of the compression machine. The top and bottom surfaces are stood on a smooth paste to make them uniform and smooth, flatness and parallelism before testing. All measuring devices were installed on specimen for measurement thoroughly at the end of the test, except for LDTs. The LDTs devices were removed before the failure of the specimen to prevent damage to LDTs devices. The LDTs measurements were removed between 60-80% of ultimate strength.

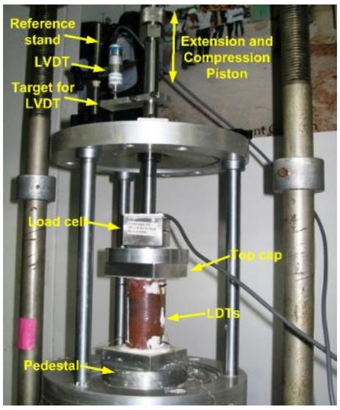

Figure 2. Unconfined compression test system and measuring devices

Experimental Program

The experimental framework of this study is to investigate the role of FA and RHA on the strength and stiffness of cement admixed lateritic with ash replacement by using the conventional unconfined compression loading tests. To get the suitable moisture, a preliminary test was performed to determine the most effective moisture content for compacting. The moisture content for mixing was kept constant at 9%. The cement content varied was at 1, 2, and 3%. The selected amount of pozzolanic materials content of 10, 20, and 30% by weight was used for replacing the Portland cement in the compacted mixture. For replacement specimens, the different cement dosages were considered by the dry weight of the C:FA or C:RHA blends. For instance, at 1% cement with 10% ashes replacement, the rations of C:FA or C:RHA were 90:10." Table 3 summarizes the mixing design for UCS test.

Table 3. Summary of design mixing ratio of the samples for unconfined compression tests

Water Content (%)	Cement content (%)	FA replaced (%)	RHA replaced (%)
	1	10, 20, 30	10, 20, 30
9	2	10, 20, 30	10, 20, 30
	3	10, 20, 30	10, 20, 30

Unconfined compressive strength (UCS) test

The UCS test was conducted following the specification of ASTM D2166-85 (ASTM, 1985). The unconfined compression machine used for this test is the displacement-controlled compression loading type having a capacity of 50 kN with a strain rate of 1% per minute. Both applied load and axial deformation were recorded simultaneously at regular time intervals until failure.

Results and Discussion

Results from the LVDT-LDT

During the test, the axial strain (ε_a) was measured by both local LDTs and an external LVDT. Figure 3 shows the relationship between axial stress (σ_a) and axial strain obtained from LVDT and LDTs devices on the 3% cement mixed lateritic specimen. It is observed that axial strain measured by LVDT is higher than that measured by LDTs. The overestimation of axial strain provided by external LVDT is occurred by the bedding errors and system compliances (Jardine *et al.*, 1984, Xu *et al.*, 2014), and practically caused by cap tilting effects that most pronounced in UCS test (Perbawa *et al.*, 2021). The specimen's instrumentation is apparent in the determination of the modulus value and shows higher impact when the test sample becomes stiffer (Zhalehjoo *et al.*, 2018). In this study, in order to avoid the LDTs damage, the LDTs were move out before reaching the ultimate state. Hence, the strain at ultimate state was measured by the LVDT only.

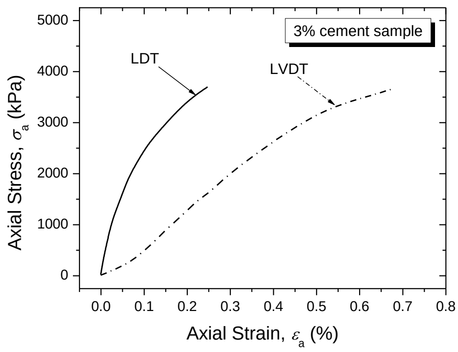

Figure 3. Monotonic loading up to 80% of ultimate strength of cement mixed lateritic (3% cement) measured by LVDT and LDTs

Strength Characteristics of Cement Treated Lateritic

Figure 4(a) and Figure 4(b) illustrate the strength characteristics between the cement-treated lateritic and the ash replacement soil specimens. The obtained results from Figure 4(a) show that the trend of increase in q_u for all specimens was remarkedly improved with cement stabilization. At the lowest cement content (1%), similar q_u values for only cement and FA replacement specimens were observed. With increasing cement content (2% and 3%), the only cement specimens exhibited higher q_u values than FA replacement specimens, with the ratio about 0.8 and 0.85, respectively. This is due to the fact that a replacement of FA content in the treated soil contributed to the lower degree of hydration reaction, resulting in a reduction in q_u value. A similar pattern can be observed for RHA replacement, as shown in Figure 4(b). At 1% of cement content, similar q_u values for only cement and RHA replacement specimens were observed. The most notable effect of the RHA replacement observed in Figure 4(b) is that a bit of difference between only cement and RHA replacement specimens is found at 2% cement content. With 3% cement content, the only cement sample shows a greater q_u value than RHA replacement samples. As a result, the ability of FA and RHA to replace the amount of cement for treating lateritic was less for higher cement content. Replacing of 1% cement by weight with FA with 10-30% was preferable. This is consistent with the results of FA replacement that it would be desirable at the sample at 1-2% cement mixed when replacing by RHA with 10-30%. The variation of the strength development for the ash replacement specimens can be discussed below:

1) For the results at 1% cement, by using 10-30% of FA and RHA, FA and RHA can be utilized to replace cement that the strength of the sample wasn't dropped. The strength development is probably due to the packing effect and pozzolanic reaction or both.

2) Based on overall results, the RHA shows a better efficiency than FA for replacement, particularly at 2% cement content. The high performance is due to the high content of SiO_2 as illustrated in Table 2, causing a relatively high pozzolanic reaction in RHA cement lateritic mixed. As shown in Figure 1, the gradations of both ashes were carefully prepared to get a comparatively same aggregate gradation, which led to a similar role of both ashes in terms of packing. As a result, the difference in the improvement of ash replacement is mainly attributed to the pozzolanic reaction.

3) At 3% cement, all ash replacement specimens show a lower strength than only cement specimens. An increase in ash content is generally not recommended. The high amount of ash replacement significantly decreased in hydration rate and consequently in strength development.

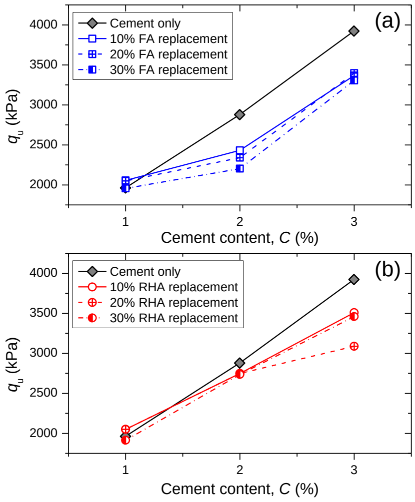

Figure 4. The relationship of cement content and unconfined compression strength in the role of (a) FA replacement (b) Rice Husk Ash replacement

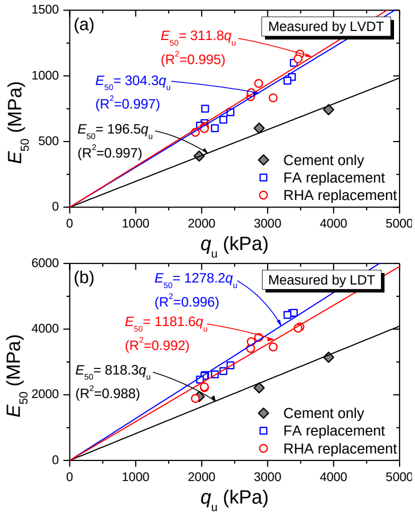

Figure 5. Relationship between Modulus of elasticity (E50)-unconfined compressive strength (qu) measured by (a) LVDT (b) LDT

Modulus of Elasticity

In the current study, the secant modulus of elasticity value is measured at 50% of q_u, namely 'E_{50}' value. For comparison, both LVDT and LDTs were used to measure the axial strain. From Figure 5(a) and Figure 5(b), the E_{50} values increase with q_u, and the linear relationship between E_{50} and q_u can be considered to fit the data. The E_{50} values obtained from LDTs are illustrated in Figure 5(a), estimated as 196.5q_u, 304.3q_u, and 311.8q_u for only cement, FA and RHA replacement samples, respectively. For LDTs results (see Figure 5(b)), the linear relationships can be approximately estimated as 813.3q_u, 1278.2q_u, and 1181.6q_u for only cement, FA, and RHA replacement samples, respectively. It can be seen that the observed E_{50} values from cement mixed with ash replacement are higher than those of only cement. As expected, the E_{50} determined from LVDT show smaller values than those determined by LDTs device. The modulus of elasticity values obtained from the local LDTs is approximately four times greater than those measured by LVDT.

Efficiency Factor of Pozzolanic materials

The use of stabilized materials for their application, in most cases, is typically based on the q_u value, which is considered to be the essential property. An accurate method of predicting strength is essential for the preliminary design of mixing ratio for both cement and cement-ash-treated soils. Several previous researches have been conducted to present the relations for estimating the strength of cement-treated soil materials. The key parameters are the water content (C_w), cement content (A_w), time, etc. For the utilization of pozzolanic materials in cement admixed soil, the pozzolanic content is evaluated as an equivalent cement content in terms of strength improvement, the so-called efficiency factor. According to the influence on strength of each mixing component is similar to that of concrete, it is reasonable to adopt the empirical equation developed in concrete research in strength analysis of this mixture (Jongpradist *et al.*, 2010). Based on Papadakis and Tsimas (2002), the efficiency of ashes in concrete technology is widely adopted by using the following equation:

$$q_u = K\left[\frac{C+kP}{W} - a\right] \quad (1)$$

where C is cement content (%), k is efficiency factor, W is total water content (%), P is ash content or Pozzolan content (%), K is coefficient (kPa), and a is coefficient largely dependent on curing time. For the cement-ash admixed clay investigation, utilization of efficiency factor for strength prediction was carried out for fly ash (Jongpradist *et al.*, 2010) and rice husk ash (Jongpradist *et al.*, 2018).

From Figure 6, k values for both pozzolanic materials decrease with increasing ash and water content. The trend of decreasing in efficiency factor is consistent with discussions that appeared in the previous section. The relationship between efficiency factor, k with $C/(W+P)$ for both ashes can be obtained as the Equation:

$$k_{FA}=0.09-10.97\,[C/(W+P)] \quad (2)$$

$$k_{RHA}=1.96-9.33[C/(W+P)] \quad (3)$$

By substituting the obtained efficiency factor into Equation 1, the unconfined compressive strength of cement-ashes treated lateritic can be obtained. The relationship between calculated unconfined compressive strength ($q_{u,cal}$) and measured unconfined compressive strength ($q_{u,mea}$) is shown in Figure 7. As can be seen from this figure, the equation presented by Papadakis and Tsimas (2002) is reasonable for predicting the strength of cement-ash treated lateritic and they also showed an insignificant difference between $q_{u,cal}$ and $q_{u,mea}$.

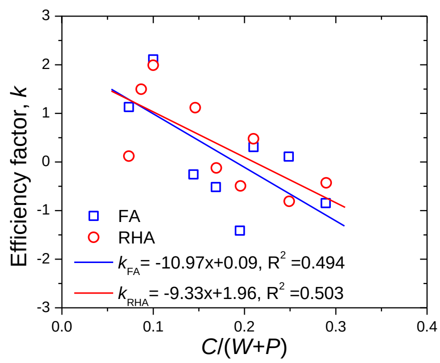

Figure 6. Relationship between efficiency factor and C/(W+P) for FA and RHA at 28 days of curing time

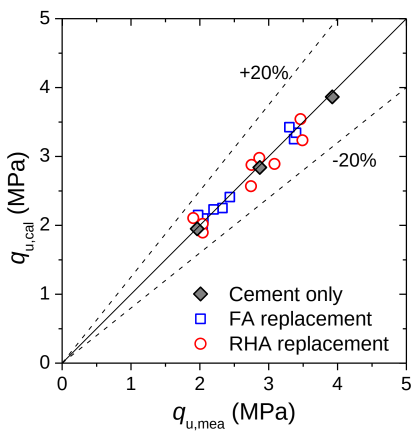

Figure 7. Correlation of predicted and measured unconfined compressive strength (ashes replacement at 1%-3% cement)

Strength Prediction by Void Ratio Concept

An empirical expression, namely "effective void ratio, e_{st}" proposed by Jongpradist *et al*. (2011) was also used in this study. This concept adopted the relationship between q_u and ratio of after curing void ratio to cement content (e_{ot}/A_w) and was used to characterize the data set of soil-cement (low void with the saturated condition) and air-cement treated soil (high void with the unsaturated condition). The results indicated that the strength characteristic of both mixtures could be reasonably captured by the parameter e_{ot}/A_w. The effective void ratio can be expressed as follows:

$$e_{st} = C_w \times \ln\left(\frac{e_{ot}}{A_w^*}\right) \quad (4)$$

$$e_{ot} = \left[\frac{(1+W_t)G_{st} \times \gamma_w}{\gamma_t} - 1\right] \quad (5)$$

where W_t is the after-curing water content after "t" curing time (in decimal), G_{st} is the after-curing specific gravity (dimensionless), γ_t is the after-curing unit weight (kN/m^3), and γ_w is the unit weight of water (kN/m^3)

Figure 8 presents the relationship between e_{st} and q_u, with an approximate R^2= 0.862. From the figure, q_u decreases with an increase of e_{st} value. The observation is broadly consistent with the trend line by Equation (4), taking into account the effects of total water content, cement content, and curing time on q_u of cement-ash treated lateritic.

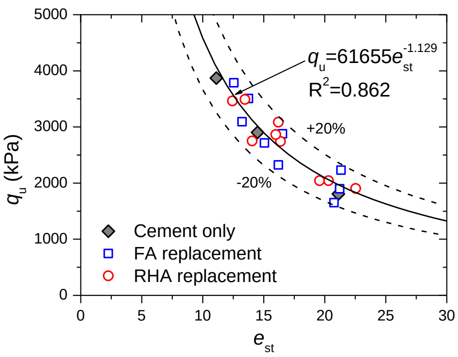

Figure 8. Variation of qu with est

Conclusions

This study was carried out to assess FA and RHA's performance for replacing the Portland cement in a cement-treated lateritic soil application. The mixed materials varying the cement content and the ash replacement percentage were compacted, and a series of unconfined compressive strength tests were carried out. The following conclusions can be derived from the test results described above:

1) The E_{50} determined from LVDT show smaller values than those determined by LDTs device, which can cause bedding errors and system compliances. The modulus of elasticity values obtained from the local LDTs is approximately four times greater than those measured by LVDT.

2) The amount of RHA at 10-30% can be replaced effectively by the cement into 1-2% cement mixed lateritic soil, while FA replacement with the same amount can be the cement in only 1% cement mixture.

3) Based on overall results, the RHA shows a better efficiency than FA for replacement, particularly at 2% cement content. The high performance is due to the high content of SiO_2.

4) Base on the empirical expressions presented from the literatures, the concept of efficiency factor and effective void ratio is reasonable to predict the strength of cement-ash treated lateritic.

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