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Potential Usage of Rice Husk Ash-Cement Based Soil in Subbase and Base Courses in Road Construction

Vu To-Anh Phan[1*], Van-Long Nguyen[2], Van-Bach Le[3], Huu-Bang Tran[4]

[1]Sustainable Developments in Civil Engineering Research Group, Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, VIETNAM

[2]Institute of Civil Engineering, Ho Chi Minh City University of Transport, Ho Chi Minh City, VIETNAM

[3]Campus in Ho Chi Minh City, University of Transport and Communications, Ho Chi Minh City, VIETNAM

[4]Faculty of Architecture, Thu Dau Mot University, Binh Duong Province, VIETNAM

*Corresponding Author

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Abstract: This paper presents an experimental study of rice husk ash-cement-based soil for layers in roadway construction. Rice husk ash (RHA) used in this study is a by-product of rice milling. In this work, twelve proportion mixes were used with varying quantities of RHA (0-30%), and Portland cement blended amounts of 4, 6, 8%. The specimens were prepared by the Proctor mould method, conditioned at room temperature, and tested in soaked and unsoaked conditions. Specified curing periods of 7, 14, 28 days were applied for all types of specimens. Some engineering tests were carried out, such as proctor compaction, unconfined compressive strength, splitting tensile strength, and the stiffness of stabilized soil. Test results indicated a general decrease in the maximum dry density (MDD) and increased optimum moisture content (OMC) with an increase in RHA content. Adding cement and RHA significantly improved the geotechnical properties of stabilized soils, including compressive strength, splitting tensile strength, elastic modulus. In addition, the combination of 80% soil and 20% RHA and 6% cement can be used as the optimum proportion, which satisfied the grade 3 of soils stabilized with inorganic adhesive substances, chemical agents, or reinforced soil for road construction, as indicated in the current Vietnamese standard.

Keywords: Geotechnical properties, stabilized soil, rice husk ash, unconfined compressive strength

1. Introduction

For the past three decades, Ordinary cement and blended cement employments have developed significantly. Ordinary Portland Cement (OPC) and Portland concrete are trendy materials in civil engineering due to their strong, durable, and cheap characteristics; however, they have significantly affected environmental drawbacks. Cement manufacture releases significantly CO_2 emissions during the limestone combustion and calcination processes [1]. The properties of clayey soils are usually characterized by compression, low shear strength, low shear capacity, and highly swell potential [2], resulting in not being capable of use in subbase and subgrade of road construction. Significantly, volume changes due to shrinkage and swelling cause road surface deformation and bearing capacity reduction [3]. To

*Corresponding author: phantoanhvu@tdtu.edu.vn

improve the geotechnical properties of soil for many purposes, many researchers focused on studying the improvement of a broad range of soil with different adhesives. Over the past four decades, many soil improvement techniques have been considered and employed in practice, including mechanical stabilization, stabilization using soft aggregates, bituminous stabilization, lime stabilization, cement stabilization, thermal stabilization, chemical stabilization, and electric stabilization [3], [4]. Recently, pozzolans from waste materials such as fly ash, rice husk ash, and slag are considered eco-friendly cementitious materials that can replace traditional materials such as OPC [4]-[9]. Various admixtures such as cement, fly ash, lime, blast-furnace slag cement, alkaline activation, eggshell powder, sodium chloride, polypropylene fiber, and calcium chloride were used in different areas in the world [6], [7], [10]-[17]. Recently, Tran et al. [18] investigated the cement – DZ33 treated soil at a site for a rural road in Vietnam and concluded that the treated soil had been improved significantly, including elastic modulus of reinforced soil, splitting tensile strength, compressive strength, and California Bearing Ratio (CBR). Rice husk Ash (RHA) is an agricultural by-product of rice milling. Over 100 million tons of rice husk are produced whole the world per year. If all rice husks had been burned, it would annually produce about 20 million tons of RHA worldwide [19]. This RHA dramatically affects the environmental hazard harming the land and the surrounding area. A literature review revealed that RHA significantly improved the strength of Portland concrete [20]. Kanthe et al. [21] indicated that using 10% RHA and 20% fly ash (FA) as partial cement replacement yields the highest compressive strength of Portland cement. Gill & Siddique [22] investigated the micro-structural properties of self-compacting concrete containing metakaolin and RHA with the fine aggregates replaced by RHA in percentages of 10, 20, and 30% and concluded that the compressive strength and splitting tensile strength results are positive.

Although many researchers have studied using lime, cement, and other additives to improve soil strength, limited research on the engineering properties of using RHA in soil stabilization has been investigated. Concerning soil stabilization, certain studies have been done in recent years. Thomas et al. [3] indicated that a combination of 20% of RHA and 2% natural lime, by weight, significantly improved the CBR value of expansive clay soil by 8 times, reduced the soil plasticity by approximately 90%, and decreased free swell by about 70% which makes more durable materials for road construction. Kumar and Gupta [23] revealed that a combination of clay, RHA, PA, cement, and fiber could be used as lightweight fill material in different structures like an embankment or retaining walls. Sani et al. [24] revealed that lean clay treated RHA in stepped concentrations of 0, 2, 4, 6, and 8% had improved the unconfined compressive strength of soil treatment. Agus Setyo [25] conducted the soil mixed with 17% lime + 17% RHA + 0.4% fibers and revealed that lime-RHA-fibres stabilized soil compacted at the optimum wet moisture content to meet the requirement as an unbound course for pavement structure.

Although available studies have been conducted in Vietnam to understand the behaviors and engineering properties of soil stabilization using cement and lime, there were no apparent reports on the engineering properties of using RHA in soil stabilization in the laboratory and the field. Soil stabilization is the process used to improve the engineering properties of the soil and make it more stable. Soil stabilization is required when the soil available for construction is unsuitable for the intended purpose, especially road construction.

Using RHA on soil stabilization materials from local materials can remarkably reduce the cost of construction, especially in road construction [3], [12], [21], [23], [26]. The present work was done to understand the use of RHA in clayey soil stabilization. The clayey soil used in this study was collected in Vinh Long province, Southern Vietnam. No research has been done in this area with cement and RHA.

This paper investigates the optimum amount of RHA for evaluating the engineering properties of rice hush ash-cement-based soil. Twelve proportion mixes were used in this work with varying quantities of RHA (0-30%) and Portland cement blended amounts of 4, 6, and 8%. The specimens were prepared by the Proctor method, conditioned at room temperature and above 80% relative humidity, and then tested with soaked and unsoaked conditions at 7, 14, and 28 days. Optimum moisture content, maximum dry unit weight, unconfined compressive strength, splitting tensile strength, and elastic modulus of stabilized soil were obtained in this study. This work presents one case as a component of a broader research effort on the properties of locally available soils for construction in Vinh Long province, located in Southern Vietnam. The experimental data provide a quantitative basis of base and subbase materials for further road construction in the study area.

2. Experimental Program

The materials used in this study composed of excavated soil, Portland Cement Blended (PCB), and RHA.

2.1 Materials

2.1.1 Excavated Soil

The soil sample for the laboratory test was taken from Vinh Long province, Southern Vietnam. The disturbed soil sample was excavated at 1m depth from the surface. Based on ASTM D422-2007 [27] method, the result of the grain size distribution curve for soil is shown in Fig. 1. Specific gravity test G_s was conducted by ASTM D854-2010 [28]. Atterberg limits were measured following ASTM D4318-2000 [29]. The plasticity index (PI) was calculated as the difference between the liquid and the plastic limits (PI = LL - PL). Geotechnical properties of undisturbed samples are listed in Table 1. According to the Unified Soil Classification System, the soil is classified as lean clay (CL).

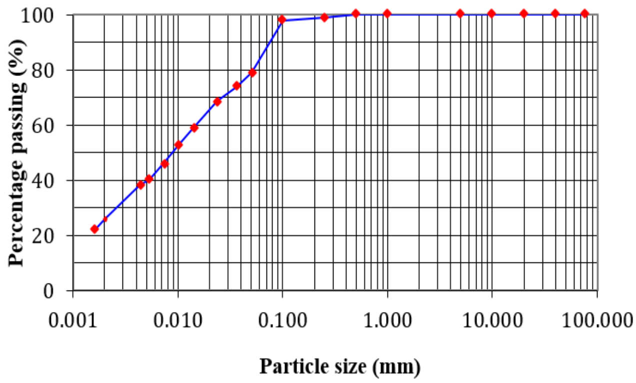

Fig. 1 - Grain size distribution of soil

Table 1 - Basic physical properties of undisturbed soil

Basic properties	Tested values
Specific gravity, Gs	2.59
Liquid limit, (%)	44.58
Plastic limit, (%)	23.37
Platic index, (%)	21.21

2.1.2 Rice Husk Ash

Rice husk ash used in this study was distributed by a local commercial company. The grain size distribution of RHA is presented in Fig. 2. Rice Husk Ash is a by-product produced from puffed rice containing a large amount of iron oxide and silica. The chemical compositions of rice husk ash are listed in Table 2.

Table 2 - Chemical composition of rice husk ash

Composition	Tested values
SiO_2	82.3%
Al_2O_3	2.0%
Fe_2O_3	1.8%
CaO	3.9%
MgO	0.4%
Loss of Ignition	9.2%

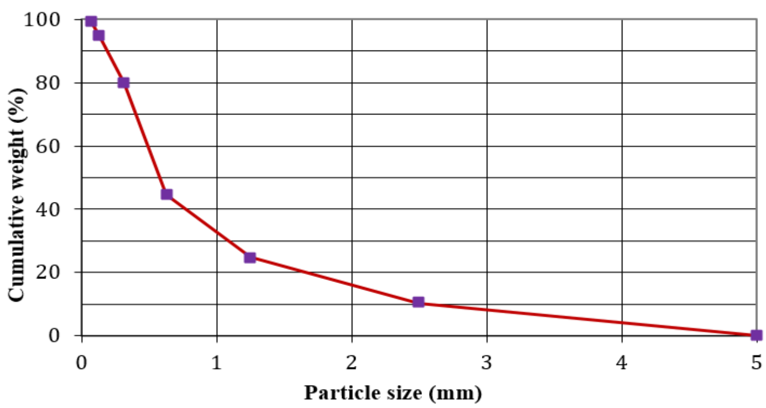

Fig. 2 - Grain size distribution of RHA

2.1.3 Portland Cement Blended (PCB 40)

PCB 40 used in this work is purchased from a local company. The strength formation of Portland cement was composed of progressive stiffening, hardening, and strength development after water was mixed. The basic properties and chemical analysis test results are listed in Table 3.

Table 3 - Properties of PCB 40

Properties		Tested results
Compressive strength, MPa		
	3 days	22.8
	28 days	47.00
Setting time, min.		
	Initial	133
	Final	172
Fineness, cm^2/g		3850
Specific gravity		3.05

2.2 Mix Proportions and Testing Methods

2.2.1 Mix Proportions

A total of 12 sets of mixed proportions were done for this experiment, as presented in Table 4. Twelve proportion mixes were used in this work with varying quantities of RHA (0-30%) and Portland cement blended amounts of 4, 6, and 8%. The specimens were conducted on twelve mix groups, namely M4.1, M4.2, M4.3, M4.4, M6.1, M6.2, M6.3, M6.4, M8.1, M8.2, M8.3, M8.4, as presented in Table 4.

Table 4 - Experiment of mix proportions

No	Mix	Mix proportion (%)			
		Soil	RHA	Cement	Curing condition
1	M4.1	100	-	4	Soaked
2	M4.2	100	-	4	Unsoaked
3	M4.3	90	10	4	Soaked
4	M4.4	90	10	4	Unsoaked
5	M6.1	100	-	6	Soaked
6	M6.2	100	-	6	Unsoaked
7	M6.3	80	20	6	Soaked
8	M6.4	80	20	6	Unsoaked
9	M8.1	100	-	8	Soaked
10	M8.2	100	-	8	Unsoaked
11	M8.3	70	30	8	Soaked
12	M8.4	70	30	8	Unsoaked

2.2.2 Testing Methods

The following are testing methods used in the experimental program:

a) Compaction test: Standard Proctor compaction tests were performed by AASHTO T99-95 [27], using method A. The specimens were of 101.6mm diameter and116mm height. The soils, RHA, and cement were manually prepared in dry material and different moisture contents to conduct tests. A metal rammer was used with a mass of 2.50 kg and a flat circular face of 50.8mm. The rammer was dropped freely from the height of 305mm. The specimen was prepared in three layers, and 25 blows compacted each layer. Finally, maximum dry unit weight and optimum moisture content were obtained through this test.

b) Soaked and unsoaked conditions: There are two curing conditions in this study, including soaked and unsoaked conditions. After preparing the specimens by proctor compaction method, the specimens were first cured in room condition (temperature of 25±2°C). The way defined the unsoaked condition was that the specimen was cured and tested in room condition until the day of testing. The soaked condition was defined as the specimens being soaked in water for 48 hours before being tested on the day of testing.

c) Unconfined compressive strength: UCS tests of stabilized soil with different RHA and cement contents for various curing ages were conducted by AASHTO T208 [28]. A metal mould prepared cylindrical specimens with 5cm in diameter and 10cm in height at the maximum dry unit weight and optimum moisture content obtained in the standard

Proctor compaction test. After that, the stabilized soil specimens were immediately packed in a plastic bag and stored in a chamber at room temperature.

d) Splitting tensile strength (STT): ASTM C496-96 [29] was used to test the splitting tensile strength of stabilized soil. The diameter and height of the specimen were 101.6 mm and 116 mm, respectively. Three specimens have been tested for each stabilized soil sample, and the average value of the result has been used for evaluation. The splitting tensile strength is calculated by Eq. [1], as follows:

$$T = \frac{2P}{\pi HD} \tag{1}$$

where T is splitting tensile strength, while H and D are the length and diameter of the specimen, respectively.

e) Stiffness of soil: The elastic modulus of stabilized materials is an important parameter required in layered elastic analysis of pavement structure. To determine the elastic modulus, the specimen with the diameter and height is 101.6 mm and 116 mm, respectively, as shown in Fig. 3. The elastic modulus test conformed to TCVN 9843-2013 [30] was used in this study.

Fig. 3 - Elastic modulus testing

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f) Specimen preparation: Specimens conducted in this study were prepared by the Proctor compaction method. Based on the maximum dry density and optimum moisture content for all mixtures, all specimens were controlled at the same dry unit weights and optimum moisture contents for each mixture obtained from the Proctor compaction test. Specimens were stored at the curing age of 7, 14, 21 and 28-day under soaked and unsoaked conditions. The average of three specimens reports the tested value.

3. Results and Discussion

3.1 Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)

The compaction significantly affected the geotechnical properties of soils, especially for subbase and base layers of road construction. Fig. 4 presents the values of MDD and OMC of soil stabilized with various RHA contents. Looking at the data shown in this figure, OMC increased with an increase in the RHA content of the mixture. This phenomenon could be explained in that RHA had a higher OMC than soil, so increasing RHA content in the mixture caused an increase in OMC of the overall mix. In addition, the MDD of soil decreased linearly with the addition of RHA. The decrease in MDD is likely attributed to the soil replacement by RHA, which has lower specific gravity as compared to pure soil. These results are found to be similar to the finding of Kuma and Gupta, who studied a combination of clay, RHA, PA, cement, and fiber for construction materials [23].

3.2 Unconfined Compressive Strength of Stabilized Soil, f'_c

Unconfined compressive strength is a common property to evaluate the strength of stabilized soil. Fig. 5 plots the variation of UCS at 7, 14, and 28-day curing ages of stabilized soil with different percentages of cement for two curing conditions, such as soaked and unsoaked curing. In general, the UCS increased as the curing period increased due to the time-dependent pozzolanic reactions. In addition, the compressive strength of cement stabilized soil increases with a percentage of cement increased in a range of 4-8%. To understand the strength of soaked and unsoaked specimens, it can be seen in Fig. 5 that the compressive strengths of unsoaked specimens are higher than that of the soaked specimen. For instance, 7-day specimen groups have the compressive strength of 0.352-0.895 MPa and 0.244-0.705MPa, corresponding to unsoaked and soaked conditions, respectively.

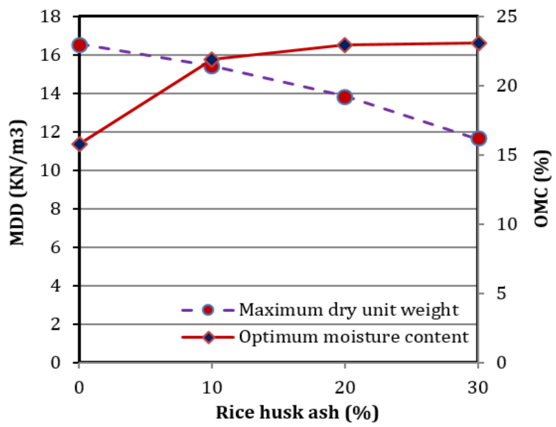

Fig. 4 - Maximum dry density and optimum moisture content with various rice husk ash contents

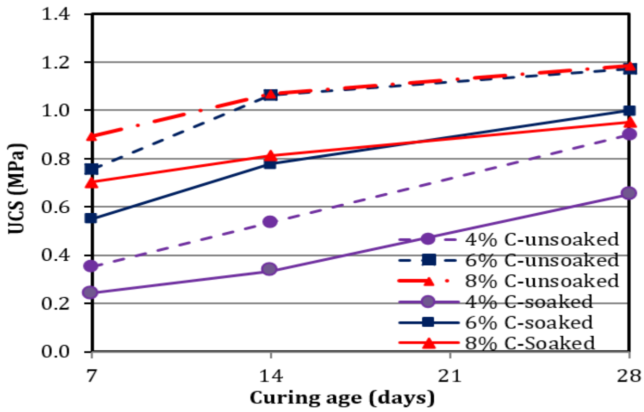

Fig. 5 - Variation of UCS with curing age for different stabilized soils containing 4, 6, and 8 % cement

Fig. 6 presents the 28-day compressive strength of stabilized soil with different percentages of cement. The compressive strength recorded was 0.653-0.899 MPa, 0.999-1.174 MPa, 0.952-1.186 MPa at 4, 6, and 8 % cement contents, respectively. It can be observed that the strength significantly increased when cement content increased from 4 % to 6 %, and after that, it slowly increased with a further increase in cement content of 8%. The results obtained in this study are found to be the same tendency of Phan [7], who studied the treatment of mudstone and cement with the dosage of 4% and 8% at different densities and concluded that 4% cement could be used as a reasonable ratio for treated mudstone.

The strength of stabilized soils with various cement and RHA contents is presented in Fig. 7. It is noted from this figure that the unsoaked specimens give higher compressive strength compared to soaked specimens, irrespective of cement content, RHA content, and curing age. For example, maximum and minimum increases of 57.71% and 22.87% were obtained, corresponding to 90% S+10% RHA+4% C specimen at 14-day and 70% S+30% RHA+8% C specimen at 28-day, respectively. As depicted in Fig. 7, 80% soil and 20% RHA, and 6% cement combined showed the highest compressive strength compared to other specimens.

The 28-day compressive strength of stabilized soil with various amounts of cement and RHA are presented in Fig. 8. Maximum compressive strength was obtained with specimens containing 80% soil, 20% RHA, and 6% cement, irrespective of unsoaked or soaked conditions. The phenomenon can be attributed to the combination of 20 % RHA and 6 % cement causing the best continuation of the cementitious-hydrated process in the mixture. Thus, it can be a reasonable ratio, making an economical and technical efficiency.

In addition, results plotted in Fig. 8 indicated that only the specimen containing 80% soil and 20% RHA and 6% cement satisfied with Grade 3 according to the requirement for soils stabilized with inorganic adhesive substances, chemical agents or reinforced composite for road construction, as described in TCVN 10379:2014 [31].

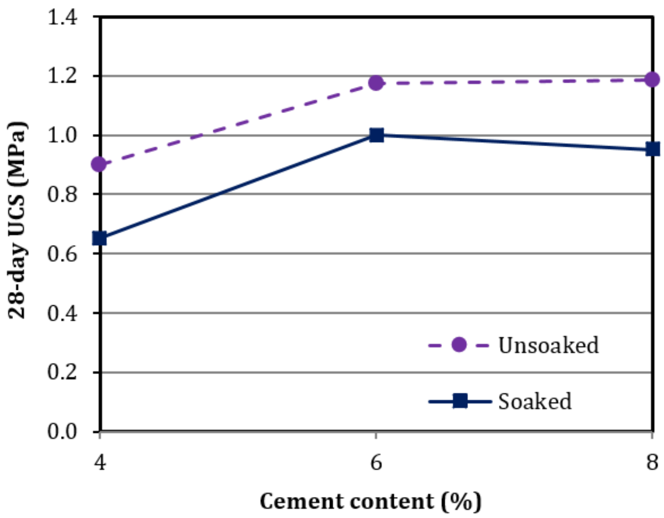

Fig. 6 - Variation of UCS at 28-day with cement content

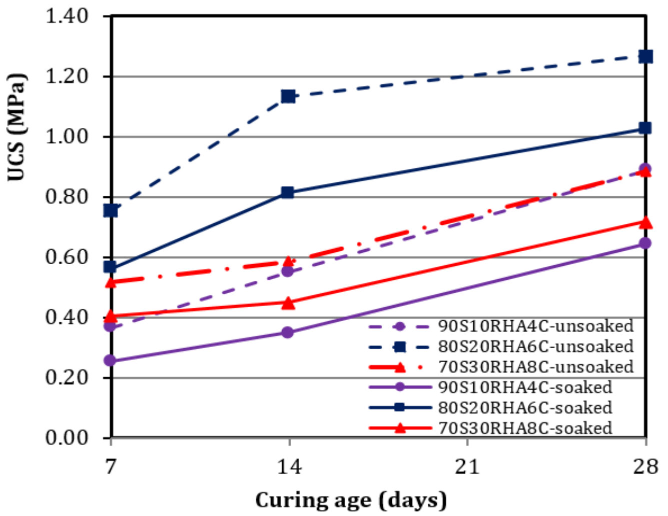

Fig. 7 - Variation of UCS with curing age for different stabilized soils containing various RHA and cement

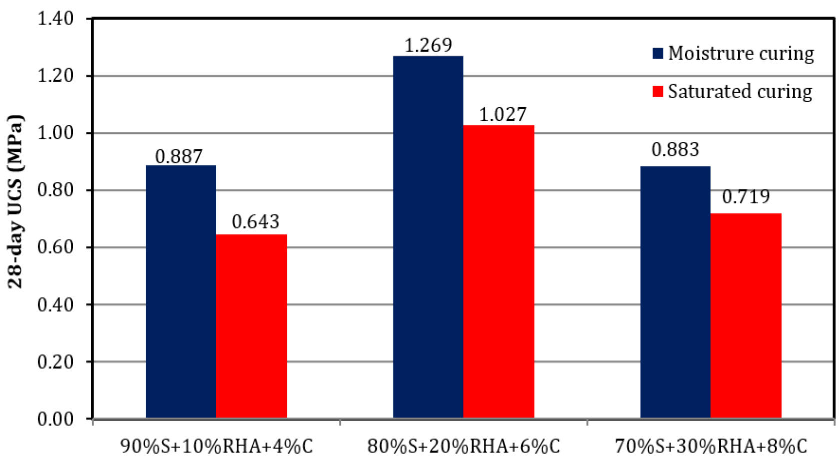

Fig. 8 - Variation of UCS at 28-day with various RHA and cement contents

3.3 Splitting Tensile Strength (STS), f'_s

Fig. 9 presents the results of STS tests on different percentages of cement and RHA content. The effects of cement content on STS have been depicted from this figure that the STS increased with an increase in cement content up to 6 %, and after that, it decreased with a cement content of 8 %. Similarly, an increase in RHA content up to 20 % caused an increase in STS; however, the increase in STS was found to be insignificant with the RHA content of 30 %. The specimen with the combination of 80% soil and 20% RHA and 6% also gave the greatest STS value compared to other specimens. This result indicated that the greater compressive strength yields a higher splitting tensile strength suitable for the basic principle of mechanical engineering.

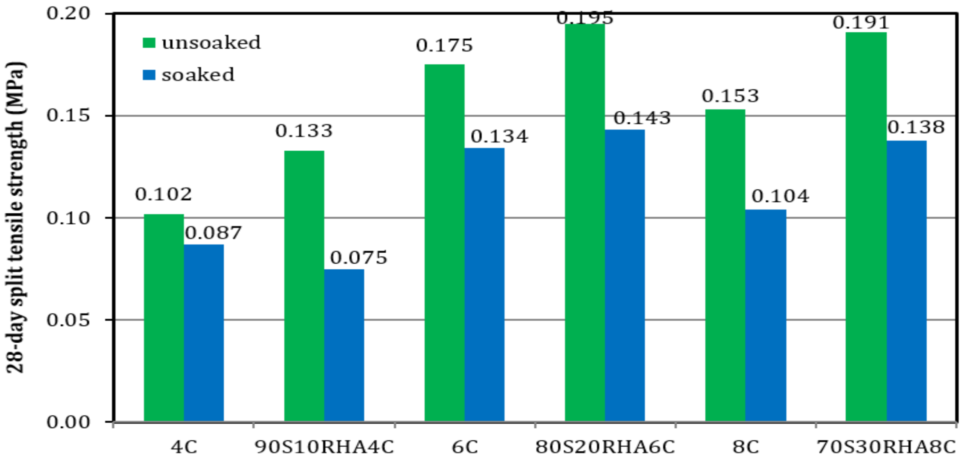

Fig. 9 - Variation of STT at 28-day with various RHA and cement contents

3.4 Elastic Modulus of Stabilized Soil, *E*

The elastic modulus of stabilized soil with different percentages of RHA and cement content is plotted in Fig. 10. The elastic modulus results were in a range of 127–227 MPa, and 88–219 MPa corresponding to unsoaked and soaked specimens, respectively. Without using RHA, a general tendency to increase elastic modulus is found with an increase in cement content of 4-8%. It is noticed that there is a significant difference between soaked and unsoaked specimens, except for specimens mixed with 80% soil and 20% RHA and 6% cement. More remarkably, the results indicated that using cement and RHA improved the elastic modulus with the cement content of 4–6 % and RHA content of 10–20%; however, the elastic modulus decreased value with the specimen containing 8% cement and 30% RHA. In addition, it is also noticed that according to Vietnamese standard, TCVN 10379-2014, only two specimens, including the specimen containing 80% soil and 20% RHA and 6% cement specimen containing 8% cement, satisfied the requirement of greater or equal to 200 MPa. The obtained data provided some specific values of elastic modulus, which are very helpful and valuable for designers as well site practice in the future in this study area; in addition, the currently stabilized soils are also contributed as a road construction material with low cost in the shortages of raw construction materials.

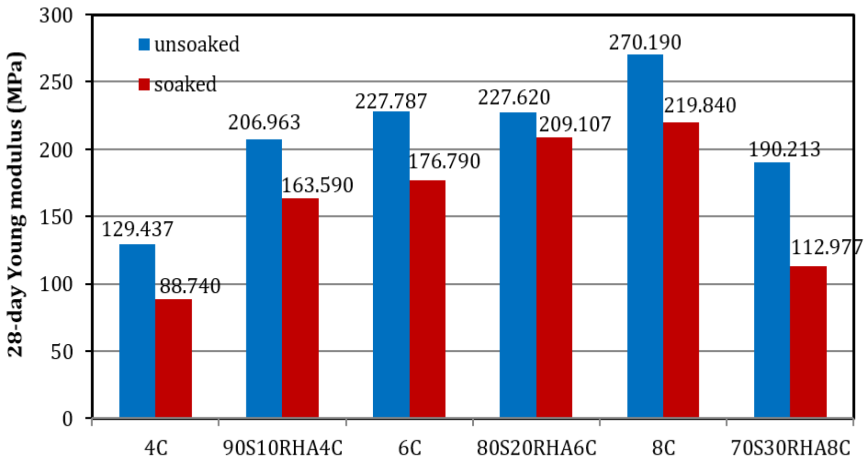

Fig. 10 - Variation of STS at 28-day with various RHA and cement contents

4. Correlation Among Obtained Data

Based on obtained data, Fig. 11 and Fig. 12 present the correlation between splitting tensile strength – compressive strength and elastic modulus-compressive strength, respectively. The splitting tensile strength and elastic modulus increased with an increase in compressive strength. An exponential equation was found with high relief, with the coefficient of determination, $R^2 \geq 0.84$. This result indicated that the higher compressive strength gave a higher splitting tensile strength and elastic modulus. It is noted that these correlations were established with consideration of all the curing days, curing conditions, cement content, and fly ash content used in this study. However, it is better to do more experiments to validate the function obtained from the study, including in the laboratory and on-site.

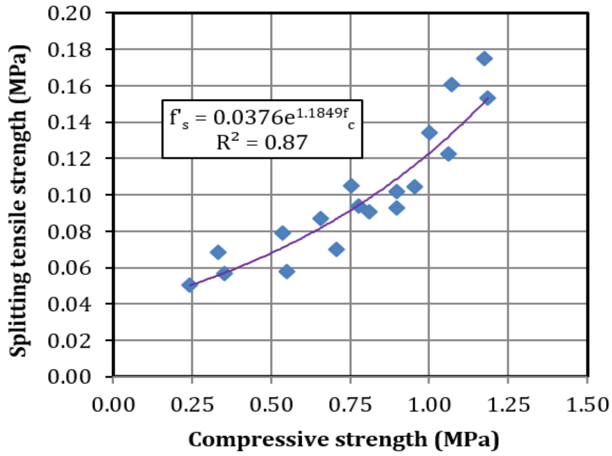

Fig. 11 - Correlation between compressive strength and splitting tensile strength

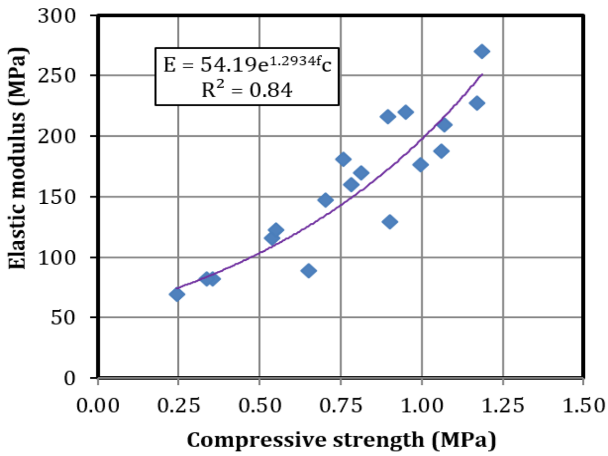

Fig. 12 - Correlation between compressive strength and elastic modulus

5. Potential Usage of RHA-Treated Soil in The Condition of Vietnam

According to TCVN 10379:2014 - Soils stabilized with inorganic adhesive substances, chemical agents, or reinforced composite for road construction, the geotechnical properties of the treated specimen must be satisfied as described in Table 5.

Table 5 - Engineering properties of treated soil based on current Vietnamese standards

Properties	Requirement			Test method
	Durability Level I	Durability Level II	Durability Level III	
1. Compressive strength (MPa)				ASTM D1633
At 28-day, soaked condition	3	2	1	
At 7-day, soaked condition	2	1	0,5	
2. Splitting tensile strength (MPa)				
At 28-day, soaked condition	1.2	0.8	-	

Table 6 presents a selected combination for treated soil using cement and fly ash for base and subbase layers in road construction. Using this value to calculate flexible and rigid pavement using the treated soil is valuable. However, these properties have been done in the laboratory. It should be validated in practice and done some tests at the site.

Table 6 - Selected value based on the data obtained

Properties	Combination	Tested value	Level III
f'_c (MPa)	80% soil+20% FA + 6% C	1.027	≥1
E (MPa)	80% soil+20% FA + 6% C	209.107	≥ 200
f'_s (MPa)	80% soil+20% FA + 6% C	0.143	No need

6. Conclusions

An experimental study was performed to obtain engineering properties of soil stabilized with cement and RHA. Some specific conclusions can be made:

- Maximum dry density and optimum moisture content decreased and increased with an increase in RHA content, respectively, which was in line with previous studies.
- Without using a percentage of RHA, the compressive strength, split tensile strength, and elastic modulus of stabilized soils significantly increased with the cement content in a range of 4-6; after that, these properties slightly increase with a further increase in cement content of 8%, except for split tensile strength.
- The unsoaked specimens gave higher mechanical properties than soaked specimens; this phenomenon may be attributed to strength reductions in the saturated condition similar to other construction materials.

An economical mixture of 80% soil and 20% RHA, and 6% cement was found, which yielded the best performance in unconfined compressive strength, splitting tensile strength, and elastic modulus. This way can explain the phenomenon that the combination of 20 % RHA and 6 % cement improved the best cementitious-hydrated process in the mixture. In addition, this combination also satisfied the requirement of geotechnical properties in current Vietnamese standards, especially for base and subbase layers in road construction, with a durability level of three.

The correlates among engineering properties were obtained from experimental investigations, such as the correlations between splitting tensile strength–compressive strength and elastic modulus-compressive strength, with the coefficient of determination, $R^2 \geq 0.84$. However, to validate the function obtained from the study, it is suggested that further study should be done more experiments, including in the laboratory and on-site. In addition, CBR should be considered for further research to have a perfect evaluation of base and subbase layers in road construction. The road usually suffered from the water during the rainy season. So CBR is the factor that evaluates the strength of mixed materials in submerged conditions.

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