EFFECT OF RICE HUSK ASH ON UNCONFINED COMPRESSIVE STRENGTH OF SOIL - CEMENT ADMIXTURE

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Received: March 29, 2020; Revised: December 21, 2020; Accepted: February 08, 2021

Abstract

Rice husk ash (RHA) is a waste product from burning rice husk and abundant in many developing countries. The utilization of RHA in combination with cement, lime for stabilization of different soils has been widely investigated and shown great potential for enhancement of soil strength. However, the utilization of RHA for soft soil improvement using cement deep mixing method is still limited, especially in Vietnam. In this study, the effect of two types of RHA obtained from uncontrolled and controlled burning conditions on the unconfined compressive strength (UCS) of cement-admixed clay will be investigated. A number of soil-cement-RHA admixtures with 10% of cement and 5 to 15% of RHA by dry weight of the soil were prepared to determine the UCS. The research results show that the type of RHA significantly affects the strength of treated soil. The UCS of soil treated with RHA from uncontrolled burning (RHA1) is lower than that of soil treated with RHA from controlled burning (RHA2). In comparison with the UCS of the controlled specimen of 10% cement only at 28 days of curing, the highest increase in the UCS of soil treated with cement and RHA1 is 6% while that of soil treated with cement and RHA2 can be larger than 50%. This indicates that the RHA from controlled burning can be beneficially added to cement-admixed clay to enhance the strength.

Keywords: **Rice husk ash (RHA), cement, RHA types, unconfined compressive strength (UCS), soft soil**

Introduction

The rice husk is a residual product from rice milling plants. It accounts for about 20% of paddy weight (Jongpradist *et al*., 2018). The rice husk is not suitable for animal feed due to its abrasive feature and low protein content. Burning is a common practice applied to dispose the rice husk. The rice husk can be burned in open heap, incinerator or used as fuel for drying fruits, power generation, biomass power plants. The residual of about 20% of the weight of rice husk remains after burning and is known as rice husk ash (RHA) (Behak, 2017; Jongpradist *et al*., 2018). A large amount of RHA is often treated as waste and disposed of to the landfill site (Alhassan and Alhaji, 2017; Jongpradist *et al*., 2018). Therefore, an increase in the utilization of RHA will have great potential to reduce waste and negative effects on the environment.

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The RHA often contains more than 70% of silica which is the highest concentration of all plant residues (Fapohunda *et al*., 2017). The amorphous silica in RHA has a little cementitious property, but it can chemically react with calcium hydroxide such as lime to form cementitious products which can enhance the strength of soil (Boateng and Skeete, 1990; Behak, 2017). Based on this feature, the RHA can be utilized to stabilize the soil. Besides, some other waste ashes have been utilized for soil stabilization such as wood ash (Krishnan *et al*., 2020), bagasse ash (Yadav *et al*., 2017; Jamnongwong *et al*., 2019), fly ash, and pond ash (Singhai and Singh, 2014; Gupta and Kumar, 2017). The RHA has been widely investigated in combination with cement or lime to stabilize local soils such as lateritic soil, residual soil, peat soil, expansive soil for base and sub-base layers in the road, pavement application, for building houses in rural areas (Rahman, 1987; Ali, 1992; 1992a; 1992b; Basha *et al*., 2005; Okafor and Okonkwo, 2009; Choobbasti *et al*., 2010; Seco *et al*., 2011; Fattah *et al*., 2013; Bagheri *et al*., 2014; Aziz *et al*., 2015; Liu *et al*., 2019a; 2019b). The RHA has been examined to partially replace cement in cement deep mixing method Yoobanpot and Jamsawang (2014) or to enhance the strength of soil-cement admixture at high water content (Jongpradist *et al*., 2018). As reported by Yoobanpot and Jamsawang (2014), the RHA could replace 30% cement in soil improvement using cement deep mixing method. In term of soil improvement, the combination of RHA with cement and/or lime will reduce plasticity index, swelling potential, swelling pressure and increase the soil strength such as unconfined compressive strength (UCS), California Bearing Ratio (CBR), tensile strength (Duong *et al*., 2020).

Traditionally, cement and lime are two chemical binders that are often used for soft soil improvement. However, the production of cement and lime often requires enormous heating and can release a huge amount of carbon emission. Besides, the price of cement and lime is often more expensive than that of RHA. Therefore, the utilization of RHA in soil stabilization not only enhances the strength of soil, but also lower the construction cost, utilize local soils, and reduce environmental problems (Alhassan and Alhaji, 2017; Behak, 2017).

The rice husk and RHA are abundant in many countries, especially in developing countries (Jongpradist *et al*., 2018). In Vietnam, the annual total yield of paddy production is about 44 million tons in 2018 (Vietnam Rice Annual Report 2018 & Outlook for 2019). It means that about 1.6 million tons of rice husk ash can be produced in Vietnam every year. This abundant amount is great potential for its utilization in engineering practice such as soft soil improvement. In Vietnam, soft soil is widely distributed, especially along the coast from Red river delta to Mekong river delta and causes a lot of problems in engineering practice (e.g., Giao and Hien, 2007; Quang and Giao, 2014; Phuc and Giao, 2020). The improvement or treatment of soft soil to meet the requirement of specific engineering construction is very necessary. The cement deep mixing (CDM) method has been used for soft soil improvement since 1975 in Japan and now widely used in many countries (Porbaha, 1998). This method injects the slurry of cement into the soft ground, mixes them and makes the increase in the strength of the ground. Currently, soft soil improvement using CDM method is also widely used in Vietnam (Suzuki *et al*., 2007; Shiwakoti and Manai, 2016; Vu, 2016; Van Bui and Pham, 2018; Vu and Le, 2020). Hence, the RHA has great potential to use as an additive or partial replacement of cement in soft soil improvement in Vietnam. However, the research on the utilization of RHA in soft soil improvement by mixing with cement is still limited. In addition, the quality of RHA significantly depends on the temperature and duration of burning rice husk and may affect the effectiveness of RHA in soil stabilization (Basha *et al*, 2005; Behak, 2017). Therefore, comprehensive research on soft soil improvement using a combination of cement and RHA with different quality needs to be conducted. In this study, the effect of two RHA types (uncontrolled and controlled burning conditions) on the unconfined compressive strength of cement-admixed clay is investigated.

Materials and Methods

Materials

Soil Sample

Soil sample was taken at the depth of 1-2 m in Thanh Hoa province, Vietnam. The soil sample is blackish grey, brownish grey clay with soft state. The particle size distribution of soil sample is shown in Figure 1. Some physico-mechanical properties of

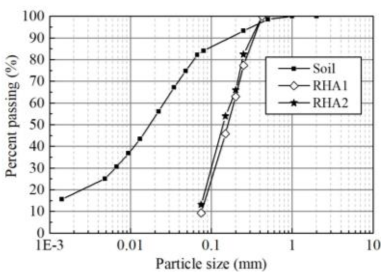


Figure 1. Particle size distribution of tested soil and two types of RH

the tested soil are listed in Table 1. The chemical composition of tested soil is presented in Table 2.

Rice Husk Ash (RHA)

In this study, RHA obtained from uncontrolled and controlled burning conditions were used. Uncontrolled RHA1 was obtained from burning rice husk in open fire for about 5-6 h whereas controlled RHA2 was obtained from burning rice husk in a furnace at a temperature of about 600°C for 2 h. As summarized in Duong *et al*. (2020), the suitable conditions to obtain the RHA with high pozzolanic property are burning rice husk under a controlled temperature of 500°C-800°C in 1-4 h. Thus, in this study, to obtain the RHA with high pozzolanic activity, the rice husk was burned in the controlled temperature of 600°C in 2 h. The burning process to obtain two types of RHA is shown in Figure 2. Selected physical property and chemical composition of both RHA types are presented in Table 3.

The RHA1 contains a high carbon content and low silica content while the RHA2 contains a low carbon content and high silica content. This indicates that the silica content in RHA from open fire burning is lower than that from burning rice husk in a furnace. Color of the RHA1 is blackish grey while that of RHA2 is whitish-grey. The lighter color of RHA shows higher content of silica and lower content of unburnt carbon (Houston, 1972). Both

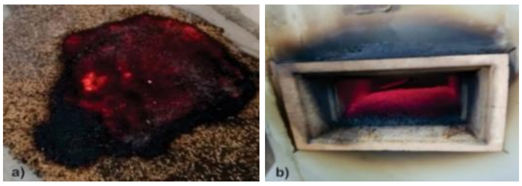


Figure 2. a) Open fire burning rice husk ; b) Burning rice husk in a furnace

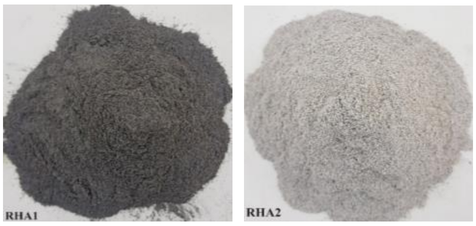


Figure 3. Two types of RHA samples used in this study

Table 1. Physico-mechanical properties of tested soil

Index property	Unit	Index value
Natural water content	%	88.0
Unit weight	g/cm^3	1.67
Dry unit weight	g/cm^3	0.89
Void ratio	-	2.026
Specific gravity	-	2.68
Liquid limit	%	91.9
Plasticity limit	%	48.4
Plasticity index	-	43.5
Liquidity index	-	0.91
Organic content	%	9.8
Unconfined compressive strength (UCS)	kPa	14.7

Table 2. Chemical composition of tested soil

Chemical composition (%)												
SiO_2	Fe_2O_3	Al_2O_3	TiO_2	MnO	Na_2O	K_2O	CaO	MgO	P_2O_5	SO_3	Cr_2O_3	Cl
53.64	7.62	20.10	2.16	0.06	0.18	1.49	0.56	1.69	0.07	2.39	0.05	<0.01

Table 3. Physical property and chemical composition of RHA

Properties	Index	RHA1 (high carbon content)	RHA2 (low carbon content)
Physical property	Specific gravity	1.94	2.24
	Color	Blackish grey	Whitish grey
Chemical composition (%)	SiO_2	58.61	77.56
	Fe_2O_3	0.17	0.40
	Al_2O_3	0.20	0.48
	TiO_2	0.03	0.04
	MnO	0.18	0.23
	Na_2O	0.03	0.07
	K_2O	3.35	5.34
	CaO	1.25	2.25
	MgO	0.71	1.21
	P_2O_5	0.63	1.02
	SO_3	1.03	3.04
	Cr_2O_3	<0.01	<0.01
	Cl	0.33	0.29
	LOI (Loss of Ignition)	33.25	8.08
	SiO_2+ Fe_2O_3+ Al_2O_3	58.98	78.44

RHA types were ground and sieved through No. 40 sieve (425 μm) for the experiment according to (Subrahmanyam *et al*., 1981; Sharma *et al*., 2008; Rao *et al*., 2012). The particle size distribution of two types of RHA is plotted in Figure 1 and the RHA samples are shown in Figure 3.

The chemical compositions of the RHA (Table 3) shows that the RHA2 can be classified class "N" pozzolan (ASTM C618, 2008), this means that this is a good pozzolan. The RHA1 with the content of SiO_2+Fe_2O_3+Al_2O_3 of 58.98% can be classified class "C". However, the LOI of RHA1 was 33.25%, it is higher than 6% maximum as required for pozzolan. This means that the RHA1 contains a high content of unburnt carbon and this will reduce the pozzolanic activity of the ash (Cordeiro *et al*., 2009).

Cement

In this study, the Portland Cement Blended (PCB40) from VICEM (Vietnam National Cement Corporation) was used. This cement is manufactured according to Vietnamese standards (TCVN 6260, 2009) and has some advantages such as high stability, ductility, and strength. The physical and chemical compositions of cement PCB40 are listed in Table 4.

Sample Preparation

A number of cylindrical remolded samples of soil-cement-RHA admixtures with the cement content of 10% and RHA contents from 0, 5, 8, 12, and 15% by dry weight of soil will be prepared and tested in the laboratory (Table 5). According to previous studies, the amount of cement used for soil improvement often ranges from 5% to 16% of the weight of the soil to be treated. Furthermore, from the view of engineering practice and economy, the binder dose used should be less than 20% of the weight of the soil (Farouk and Shahien, 2013). Hence, 10% of Portland cement was used in this study. A metal mold with 50 mm in inner diameter and 100 mm in length was used for sample preparation for the UCS test. The size of the remolded specimen in this study is in accordance with TCVN 9403 (2012) and is also used in previous studies to determine the UCS of remolded specimens (Miura *et al*., 2001; Chew *et al*., 2004; Horpibulsuk *et al*., 2005; 2011; Yoobanpot and Jamsawang, 2014). The admixture samples were created by mixing soil, cement, water, and RHA. The mixture samples of 10% cement and 0% RHA was used as the controlled sample.

Firstly, the natural soil sample was mixed for 5-10 min using a mixer (Figure 4) to the form of a slurry. The cement slurry with water/cement ratio of 1 and RHA was then added to the soil slurry and mixed again. The slurry of soil admixtures was then placed into the metal mold in three layers. Each layer was compacted by the tamper for about 1 min. The surface of the specimen in the mold was flattened and weighted to determine the mass. After 3 days, specimens were then sealed tightly using a plastic sheet to prevent loss of moisture content. All the treated specimens were subjected to curing at room humidity of 50±5% and temperature of about 20±2°C for 7, 14, and 28 days before testing. Three specimens per formula were prepared to determine the average UCS.

Table 4. Physical property and chemical composition of Portland cement PCB40

Property	Index	Value
Physical property	Specific gravity	3.10
	Unit weight (kg/m^3)	1,310
Chemical composition (%)	SiO_2	20.22
	Fe_2O_3	3.15
	Al_2O_3	5.05
	SO_3	1.45
	CaO	63.5
	MgO	0.15
	K_2O	0.70
	Na_2O	0.21

Table 5. Proportion of soil-cement-RHA mixture

No.	Cement content (%)	RHA content (%)	
		RHA1	RHA2
1	10	0	0
2	10	5	5
3	10	8	8
4	10	12	12
5	10	15	15

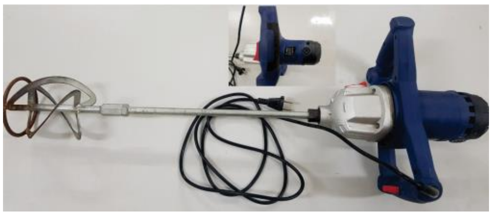


Figure 4. The mixer used for sample preparation

Methods

The unconfined compressive strength (UCS) test was performed on cylindrical remolded specimens in accordance with (ASTM D2166, 2000). The rate of loading for the unconfined compressive tests was maintained at 1 mm/min (equal to the strain of 1%/min). This rate of loading was often used to determine the UCS parameter of remolded specimens (e.g., Miura *et al*., 2001; Horpibulsuk *et al*., 2005; 2011)

Test Results and Discussions

Effect of RHA Types on UCS

The average UCS of soil treated with 10% cement and varied RHA contents are presented in Figure 5. In general, the UCS of soil treated with cement and RHA2 is higher than that of soil treated with cement and RHA1 for all RHA contents and curing periods. As reported, the pozzolanic activity of RHA was responsible for the improvement of soil, especially in terms of soil strength (Boateng and Skeete, 1990; Behak, 2017). The pozzolanic activity increased with the increase of silica content and its amorphousness degree (Nguyen, 2011). In this study, the RHA1 obtained from the open fire burning contains low silica content and high unburnt carbon content compared to RHA2 obtained from controlled burning. Hence, the low silica content in RHA1 will result in the low enhancement of soil strength. As reported by Rodrigues *et al*. (2010), the RHA with high silica content could improve the durability and strength of cellulose-cement composites better than the RHA with low silica content. Furthermore, the high unburnt carbon content in RHA1 can impede both the hydration process and the interaction between soil particles and the hydration products. This behavior is the same with the addition of cement to soil containing high organic matter (Chen and Wang, 2006; Tremblay *et al*., 2002). Therefore, the strength of soil treated with RHA1 is lower than that of the soil treated with RHA2.

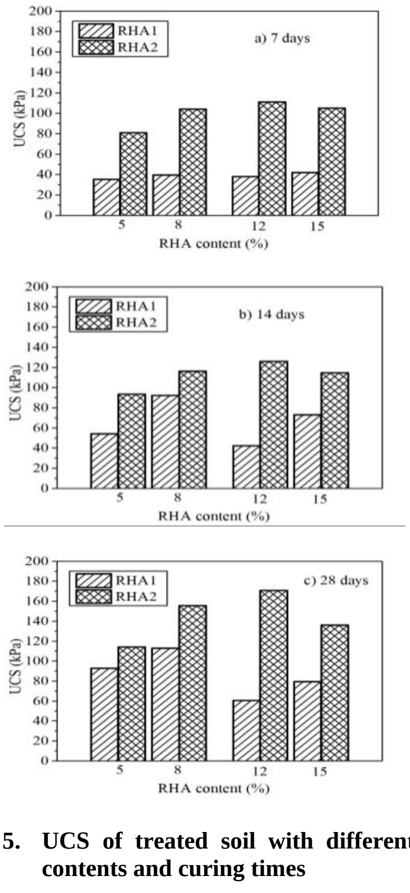


Figure 5. UCS of treated soil with different RHA contents and curing times

Development and Variation Of UCS of Treated Soil

The strength development of treated soil with different RHA contents and at different curing periods is shown in Figure 6. In general, for all RHA content of both types, the UCS values of treated soil increase as the curing time increases**.** This tendency was also observed in previous studies regarding the combination of cement and RHA in soil improvement (Yoobanpot and Jamsawang, 2014; Jongpradist *et al*., 2018). The increase of UCS values of treated soil with cement and RHA over curing time is attributed to the increase in the formation of CSH (calcium-silicate-hydrate) gel. The CSH gel is one of the main products of the hydration of Portland cement which plays an important role in increasing the strength and durability of cement mixtures (Yoobanpot and Jamsawang, 2014). Based on the Scanning Electron Microscopy (SEM) images, Yoobanpot and Jamsawang (2014) also reported that the CSH gel of soil-cement-RHA mixtures increased significantly from 307 count.s^{-1} to 774 count.s^{-1} whereas, for soil-cement mixtures, the CSH gel increased from 339 count.s^{-1} to 698 count.s^{-1} when the curing time increased from 3 days to 28 days.

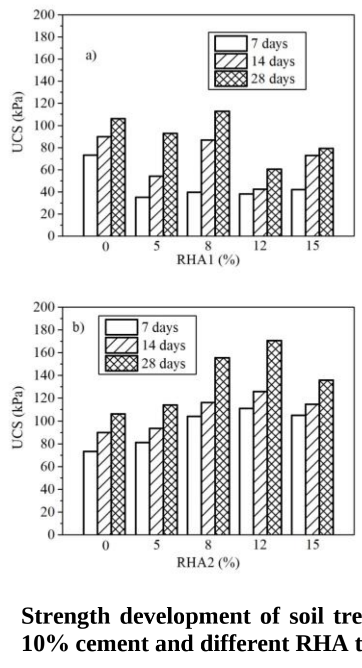
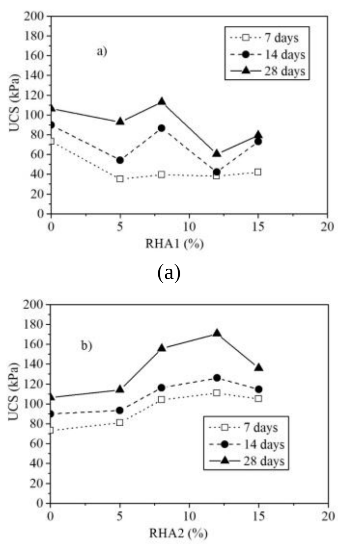


Figure 6. Strength development of soil treated with 10% cement and different RHA types

The variation of UCS of soil treated with 10% cement and different RHA contents from 5 to 15% is plotted in Figure 7. The UCS of treated soil depends on the RHA content for both types of RHA at all curing periods**.** For RHA1 (Figure 7(a)), at 7 and 14 days of curing, the controlled samples (10% cement only) produces the highest UCS values**.** This decreases with an increase in RHA content, especially at 7 days with the addition of 5% RHA. At above 5% RHA, the UCS of treated samples at 7 days was almost the same. The research results of Yoobanpot and Jamsawang (2014) also indicated that at 3 days of curing, the increase of RHA content led to a decrease in the UCS values of treated soil. Jongpradist *et al*. (2018) reported that at 7 days of curing, the addition of RHA would lead to the decrease of strength of the soil**-**cement mixtures, especially mixtures with 10% cement**.** The reason here can be attributed to the slow pozzolanic reaction of amorphous silica in RHA. It means that at a short time of curing, the pozzolanic reaction has not fully occurred to form CSH gel. In this study, the RHA1 has a low amorphous silica content and high carbon content. Thus, the pozzolanic reaction can be impeded by the unburnt carbon content and take more time to form CSH gel. At 28-day curing time, the UCS of treated soil also slightly decreases with the addition of 5% RHA. However, it then increases and reaches the highest value of UCS with the addition of 8% RHA**.** This UCS value is slightly higher than that of the controlled specimen at 28 days of curing**.** In other words, 8% of RHA1 can be an optimum content for stabilizing soft soil with 10% cement (Figure 7(a)). Nevertheless, the increase in UCS strength of treated soil at 28 days of curing is small at about 6%. The small increase here can be attributed to the low pozzolanic activity and high unburnt carbon content of RHA1**.** Therefore, in terms of soil strength, the RHA from uncontrolled burning has little potential for stabilizing soft soil with 10% cement**.** In this case, the content of cement used should be higher than 10% as suggested by Jongpradist *et al*. (2018) to increase the effectiveness of RHA in soil improvement.

For RHA2, as shown in (Figure 7(b)), the UCS of treated specimens with different RHA contents at 7, 14, and 28 days of curing is higher than that of the controlled specimen. The UCS of treated specimens significantly increases with the addition of RHA from 5 to 12%. With above 12% of RHA, the UCS of treated soil tends to decrease. This tendency well agrees with that of Yoobanpot and Jamsawang (2014). According to Yoobanpot and Jamsawang (2014), the UCS values of treated soil at 7, 14, and 28 days of curing increased with the addition of 30% RHA replacement cement and then decreased with 40% RHA replacement cement. In the research of Yoobanpot and Jamsawang (2014), 30% and 40% of RHA replacement cement equal to 17.87 % cement +7.65% RHA and 15.31% cement +10.21% RHA in respective. At 28 days of curing, the UCS of treated soil with the addition of 30% RHA replacement cement increased about 12% over that for the controlled specimen (% RHA replacement). In the present study, the UCS of treated soil at 28 days of curing can increase by up to 52.1% for the addition of 10% cement and 12% RHA compared to that of the controlled specimen. This result shows a high potential of using RHA from controlled burning for soft soil stabilization in combination with cement. For RHA from controlled burning, the research of Jongpradist *et al*. (2018) indicated that the RHA could increase the UCS of cement**-**admixed clay up to more than 100% depending on mixing components. Generally, the RHA content from 5 to 35% could enhance the strength of cement**-**admixed clay about 50% (Jongpradist *et al*., 2018).

In general, for both RHA types, the UCS of treated soil increases as the RHA content increases at curing time from 7 to 28 days**.** This is because the RHA leads to an increase in the formation of CSH gel which enhances the soil strength**.** The analysis of SEM images indicated that the CSH gel of soil**-**cement**-**RHA mixtures was higher than that of soil**-**cement mixture for curing time from 7 to 28 days (Yoobanpot and Jamsawang, 2014). However, the UCS increases when RHA content increases to a threshold. It then tends to decrease with increasing RHA above the threshold value. This phenomenon



(a) (b)

Figure 7. Variation of UCS of treated soil with 10% cement and different RHA contents

Table 6. Water content of treated soil at different curing periods

%RHA	Water content (%)					
	7 days		14 days		28 days	
	RHA1	RHA2	RHA1	RHA2	RHA1	RHA2
0	86.8	86.8	82.5	82.5	78.6	78.6
5	86.2	85.8	81.5	80.4	75.3	76.0
8	84.1	83.5	79.3	79.2	72.9	73.7
12	83.4	82.1	80.2	78.1	71.9	72.8
15	81.2	80.2	75.6	77.0	68.1	71.6

was also observed in previous studies (e.g., Rahman, 1987; Ali *et al*., 1992a, Basha *et al*., 2005, Yoobanpot and Jamsawang, 2014, Khan *et al*., 2016). The decrease in UCS with increasing RHA can be attributed to the characteristics of RHA. Since RHA is a non-plastic material, the increase of RHA above the threshold can lead to a decrease in the cohesion among particles and decreases the soil strength. Besides, the increase of RHA can lead to an insufficiency of water for the pozzolanic reaction and decreases the soil strength. This behavior of RHA is the same with the behavior of adding granulated blast furnace slag (GBFS) and ground granulated blast furnace slag (GGBFS) to the soil mixture (Sharma and Sivapullaiah, 2016; Sekhar *et al*., 2017).

Water Contents of Cement-Admixed Clay at Different Curing Periods

Changes of the water content of treated soil with 10% cement and different RHA contents at curing periods of 7 to 28 days are listed in Table 6. In general, the water content of all mixtures decreases with increasing curing time and RHA content. In addition, the type of RHA has an insignificant effect on the change of water content of treated soil. The decrease in the water content was assumed due to the hydration process or pozzolanic reaction and it related to the soil strength (Yoobanpot and Jamsawang, 2014). Besides, the decrease in the water content with increasing RHA content can be attributed to the high capacity of water absorption of RHA (Adajar *et al*, 2019; Liu *et al*., 2019b).

Conclusions

In this study, the effect of two types of RHA on the cement-admixed soft clay has been thoroughly investigated. Ground RHA contents from 5% to 15% and cement content of 10% were used to mix with soft clay in the laboratory. Based on the test results, some conclusions are drawn as follows:

The type of RHA obtained from different burning conditions significantly affects the strength of treated soil. The UCS of soil treated with RHA from uncontrolled burning (RHA1) is lower than that of soil treated with RHA from controlled burning (RHA2). The low strength of soil treated with RHA1 can be attributed to the low pozzolanic activity and high unburnt carbon content in RHA.

For all RHA contents of both types, the UCS of treated soil increases with increasing curing time. In addition, the UCS of treated soil depends on the content of RHA. For RHA1 obtained from open fire burning, the highest UCS of 10% cement-admixed clay at 28 days of curing was obtained when 8% of RHA1 was added and it increased by only 6% compared with that of the cement-admixed clay without RHA. Whereas, for RHA2 obtained from controlled burning in a furnace, the highest UCS of 10% cement-admixed clay at 28 days of curing was reached when 12% of RHA2 was used and it could increase by more than 50% compared with that of the cement-admixed clay without RHA. Therefore, the RHA obtained from controlled burning could be beneficially added into cement deep mixing to increase the soil strength.

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