EFFECT OF DIFFERENT TYPES OF RICE HUSK ASH ON SOME GEOTECHNICAL PROPERTIES OF CEMENT-ADMIXED SOIL

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ABSTRACT

Rice husk ash (RHA) is an agricultural residue and has shown great potential for soil stabilization. However, the research on the utilization of RHA for soft soil improvement using cement deep mixing method is still limited and the efficiency of using different RHA types for soil improvement needs to be clarified. In this study, the effect of different RHA types on Atterberg limits, unconfined compressive strength (UCS), and elastic modulus (E_{50}) of soil-cement mixtures will be investigated. Two types of RHA which obtained from open fire burning (RHA1) and burning in a furnace under controlled conditions of temperature and duration of burning (RHA2), were used for this study. The RHA contents from 0 to 15% and 10% cement of the dry weight of the soil were used to treat the soft soil. The research results show that the types of RHA insignificantly affect the change in Atterberg limits of cement-admixed soil. Regarding the soil strength, the RHA2 shows a higher efficiency in the enhancement of treated soil strength at 28 days of curing than the RHA1. The addition of 12% RHA2 to the cement-admixed soil can increase the UCS and E_{50} values of treated soil by more than 50%.

INTRODUCTION

Recently, the use of industrial and agricultural wastes such as fly ash, steel slag, blast furnace slag, rice husk ash (RHA), wood ash, and bagasse ash in civil engineering applications is one of the great interests and has received much attention from the literature (e.g., James and Pandian, 2016; Jayanthi and Singh, 2016; Kuntikana and Singh, 2017 and Varaprasad et al., 2020). The utilization of these wastes could reduce the amount of landfilled, replace natural aggregates such as sand, gravel or even conventional Portland cement as well as reduce the construction cost. However, the utilization of RHA as a pozzolanic material in civil engineering is still limited. Rice husk ash

(RHA) is an agricultural-by product that is abundant in many developing countries such as China, India, the USA, Brazil, and Southeast Asia (Hossain et al., 2018). The ash is porous, lightweight, and contains a high content of silica with above 70%, even up to 98% (Fapohunda et al., 2017). However, the RHA is often treated as waste and disposed of to the environment and may cause a serious problem for the air and water environments, and human health. Thus, it is necessary to increase the utilization of this waste in civil engineering application to reduce the negative effect on the environment and reduce the construction cost as well.

One of the civil engineering applications that can utilize the RHA is soil improvement. The silica in RHA can be reacted with calcium hydroxide in lime and cement to form the cementitious products which can enhance the soil strength. Thi Nu et al. 2020 mentioned that the increase in salt and alum contents caused a decrease in undrained shear strength and an increase in liquid limit and compression index. Thus, the salt content in soil can impact many fields (Al-Hamdani et al., 2016). Many investigations have been conducted to examine the suitability of soil stabilization with RHA and cement (Hossain, 2011; Basha et al., 2005; Jongpradist et al., 2018; Rahman, 1987; Roy, 2014; Yoobanpot and Jamsawang, 2014). However, most of these investigations examined the utilization of RHA to stabilize soils for base and sub-base layers in pavement and road applications. Recently, Jongpradist et al. (2018) have investigated the use of RHA as a cementitious material in high-strength cement-admixed clay in the cement deep mixing method. In their research, the RHA and cement contents used ranged from 5 to 35% and 10 to 30% respectively. The research results found that the RHA significantly improved the strength of soil-cement admixtures with the cement content above 20%. However, according to Farouk and Shahien (2013), from the literature, the amount of cement used in the soil-cement column is typically ranged from 5 to 16% of the weight of the soil (Farouk and Shahien, 2013). Therefore, the use of RHA in combination with cement content in the typical range for cement deep mixing method should be extensively examined. Furthermore, the quality of RHA that is the content of amorphous silica in RHA significantly depends on the burning condition (temperature and duration of burning). The amount of amorphous silica will affect the pozzolanic reaction and the formation of gel CSH (Behak, 2017). However, the effect of different types of RHA on the efficiency of soil improvement is rarely examined. In Vietnam, burning rice residue, including rice husk, in open fire is very common, especially in rural areas (Lasko and Vadrevu, 2018 and Thao et al., 2011). Thus, the use of RHA from this condition for soil improvement should be investigated. In this study, the effect

of two types of RHA, including the RHA obtained from open fire burning and the RHA obtained from burning in controlled conditions of temperature and duration, on some geotechnical properties of cement-admixed soil will be investigated. The amount of RHA of 5, 8, 12, and 15% and cement content of 10% of the dry weight of the soil to be treated were used for this investigation. The Atterberg limits of soil-cement-RHA admixtures were determined; the unconfined compressive strength and elastic modulus (E_{50}) of admixtures were determined at 28 days of curing.

MATERIALS AND METHODS

Burning Rice Husk and Properties of Rice Husk Ash

The temperature and duration of burning rice husk significantly affect the quality of RHA. Behak (2017) found that the RHA from burning rice husk in a controlled temperature of 650^0C-800^0C (in incinerator) was more reactive than that from burning in uncontrolled temperature (in conventional ovens). Cordeiro et al. (2009) revealed that the RHA obtained from uncontrolled burning conditions often contained high carbon content with low pozzolanic activity. Nguyen et al. (2011) also stated that the RHA with high reactive silica content cannot be obtained from open burning of rice husk and burning rice husk below the temperature of 500^0C. Under uncontrolled conditions, the RHA from bio-mass power plants and open burning were not fully burned and contained a high carbon content and high loss of ignition (LOI) (Karatai et al., 2016 and Liu et al., 2019b, 2019a). Therefore, burning rice husk in controlled conditions of temperature and time is often used to produce RHA with high pozzolanic activity.

However, burning rice husk in the open fire under uncontrolled conditions of burning temperature and time is popular in Vietnam, especially in rural areas. In this study, the rice husk ash from open fire burning (RHA1) and from controlled burning conditions (RHA2) were collected. In open fire, the rice husk was burned for about 5-6 hours to obtain RHA1. The RHA2 was obtained from burning rice husk in a furnace at a temperature of 600^0C and 2 hours of burning. The RHA after collecting was ground and passed through the sieve of No. 40 (425µm). The physical properties and chemical compositions of two types of RHA are shown in Table 1. The RHA1 contains a lower content of silica, a higher content of LOI compared to the RHA2. Regarding the color, the color of RHA2 is lighter than that of RHA1 (Fig. 1). This result is consistent with the statement of Houston (1972). Accordingly, the lighter color of RHA2 is a result of a higher content of silica.
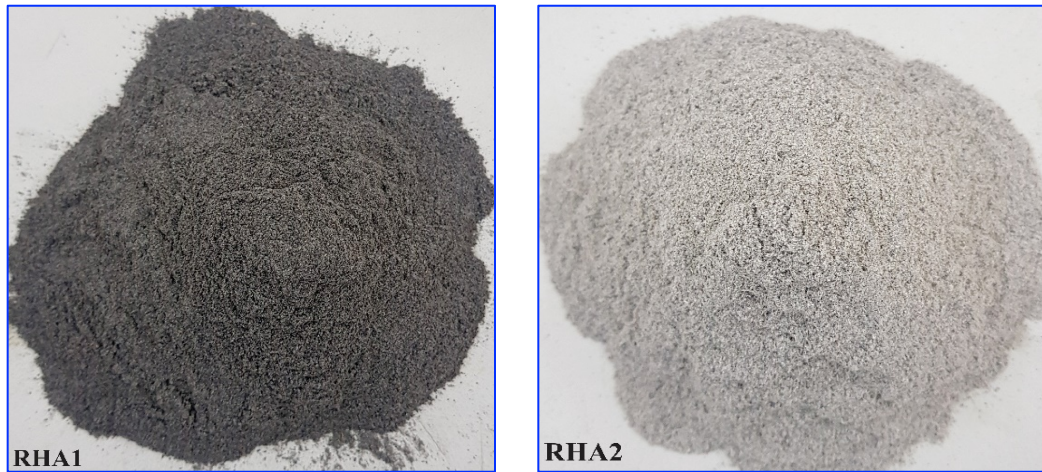
Fig. 1. The color of ground RHA used in this study

Table 1. Physical properties and chemical compositions of RHA used in this study

Properties		RHA1 (high carbon content)	RHA2 (low carbon content)
Specific gravity		1.94	2.24
Physical properties	Color	Blackish grey	Whitish grey
Chemical compositions (%)	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

Soil and Cement

The soil sample was collected from the borehole at the depth of 1-2 m in Thanh Hoa province, Vietnam. The size of soil particles is shown in Fig. 2. Some physio-mechanical properties of

studied soil are presented in Table 2. The studied soil is blackish grey, brownish grey clay with the soft state and the content of organic matter in the soil is rather high with 9.8%. The strength of the soil sample is very low with the unconfined compressive strength (UCS) value of 14.7 kPa. In this study, the Portland cement PCB40 from VICEM (Vietnam National Cement Corporation) was used. This cement contains 63.5% CaO, 20.22% SiO_2, and 16.28% for other compositions such as Fe_2O_3, Al_2O_3, SO_3.
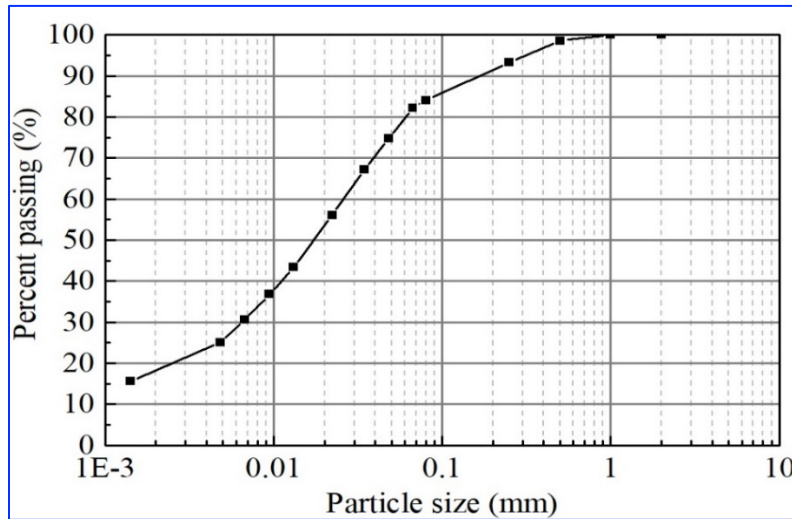

Fig. 2. Particle size distribution of soil sample used

Table 2. Properties of soil sample

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 matter	%	9.8
Unconfined compressive strength (UCS)	kPa	14.7

Sample Preparation and Method

The Atterberg limits of soil-cement-RHA admixtures were determined at 0 day of curing (0 day after mixing) following ASTM D4318-00.

For UCS tests, the soil-cement-RHA admixtures were prepared in the metal cylindrical mold with a height of 10 cm, a diameter of 5 cm. This size of the sample for determination of UCS values was also used in the previous studies (Horpibulsuk et al., 2011, 2005; Chew et al., 2004; Miura et al., 2001; Yoobanpot and Jamsawang, 2014). The admixtures in the form of slurry were created by mixing soil with 10% cement and different RHA contents of 5, 8, 12, and 15% in a mixer for about 5 to 10 minutes. The admixture of soil with 10% cement and 0% RHA was also prepared for a controlled sample. In all admixtures, the ratio of water to cement is 1. The slurry of admixtures was then placed and compacted into the metal mold in three layers. The surface of the sample was flattened, and the sample was then weighted. After three days of molding, the specimens were removed from the mold and were then sealed using a plastic box to maintain the moisture content. All the specimens were cured at room humidity and temperature for 28 days before testing. The UCS values of soil-cement-RHA admixtures were determined in accordance with ASTM D2166-00 with the loading rate of 1 mm/min. The elastic modulus (E_{50}) that was the secant modulus at 50% of compressive strength was also calculated.

TEST RESULTS AND DISCUSSIONS

Atterberg Limit

The results of the liquid limit (LL), plasticity limit (PL), and plasticity index (PI) of soil-cement-RHA admixtures are shown in Fig. 3. For both types of RHA, the LL and PL values slightly increase as the RHA content increases. However, the increase of PL is more pronounced than that of LL. The tendency of LL and PL after adding RHA to soil-cement mixtures observed in this study is similar to that after adding cement or RHA to soil observed in previous studies (Basha et al., 2005). The increase of LL can be attributed to the more water needed for the soil fluid when the RHA is added (Okafor and Okonkwo, 2009 and Sarkar et al., 2012). The increase of PL can be due to the pozzolanic characteristics of RHA (Fattah et al., 2013 and Sarkar et al., 2012). The plasticity index of soil treated with cement and RHA shows a general decrease trend. In which, the PI of soil treated with cement and RHA1 decreases from 41.2 to 35.3%, while that of soil treated with cement and RHA2 decreases from 41.2 to 35.5%. This indicates that the types of RHA insignificantly affect the change in the plasticity index of soil treated with cement and RHA.
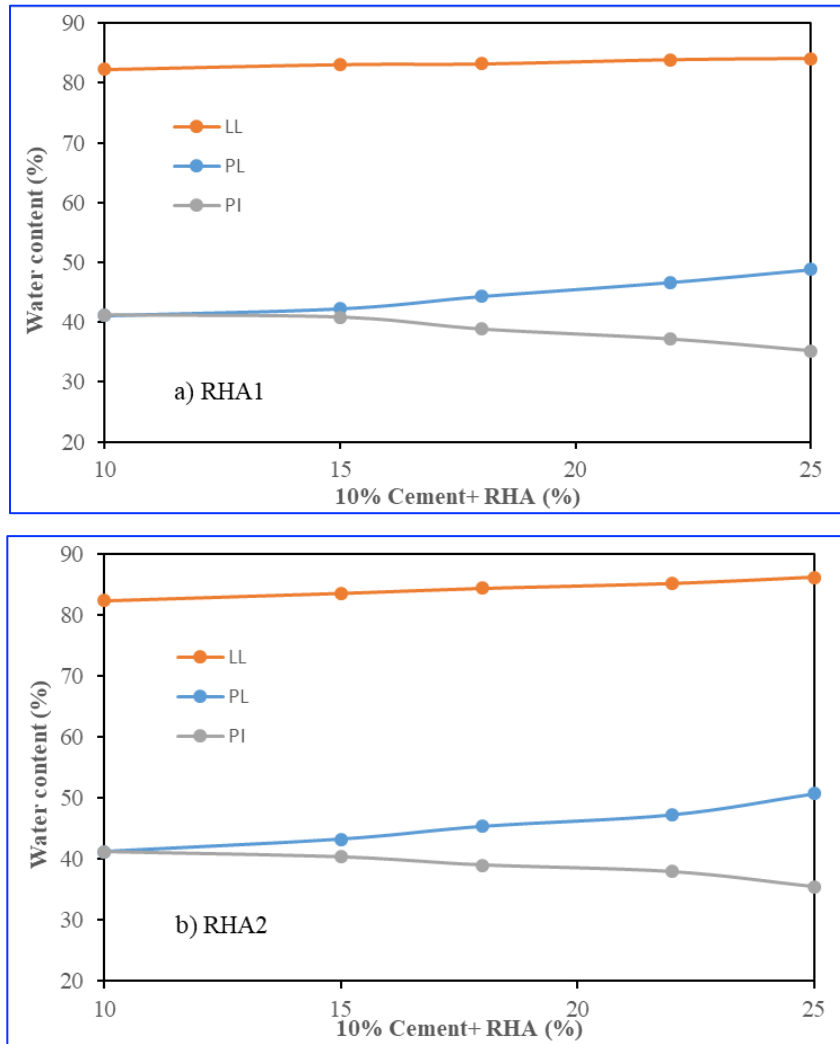
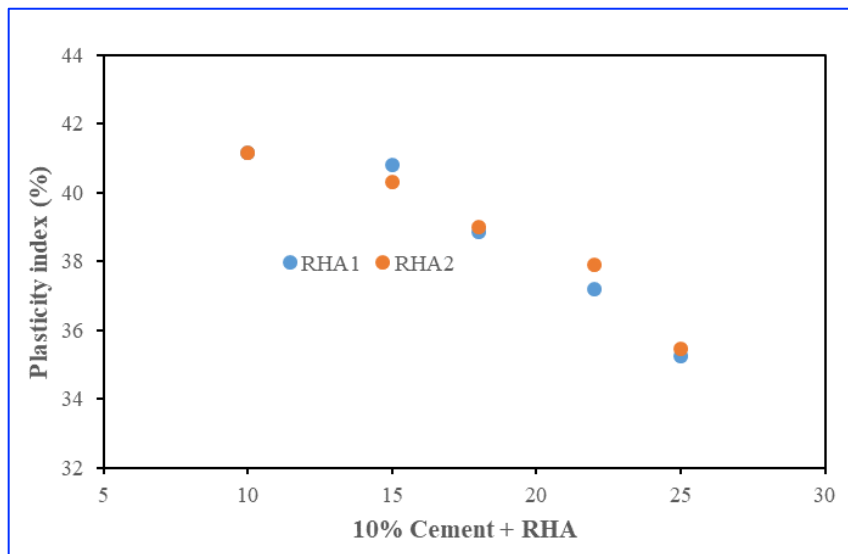**Fig. 3. Variation of Atterberg limits of soil-cement-RHA admixtures**

Fig. 4. Effect of RHA on the PI of treated soil with cement and RHA

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Unconfined Compressive Strength and Elastic Modulus

The results of UCS from the unconfined compression test and calculated elastic modulus (E_{50}) are shown in Table 3. The variation of UCS of soil treated with cement and different RHA contents is shown in Fig. 5. The increase in the content of RHA1 leads to a slight increase in the UCS values. However, the increase in the content of RHA2 leads to a significant increase in UCS values. The highest UCS of soil treated with 10% cement and different types of RHA was observed at 8% RHA1 and 12% RHA2 (Fig. 5).

Nevertheless, the addition of 8% RHA1 to the soil-cement mixture increases only about 6% of UCS values while the addition of 12% RHA2 can lead to more than 50% increase in UCS values. This increases that the pozzolanic activity of RHA2 is significantly higher than that of RHA1. This is attributed to the difference in burning conditions. In other words, the RHA obtained from controlled burning can result in a higher soil strength enhancement compared to the RHA obtained from uncontrolled burning. For both types of RHA, the RHA increasing above the optimum content will result in a decrease of UCS.

This tendency is also observed in previous studies. Yoobanpot and Jamsawang (2014) showed that the highest UCS of soil-cement admixture was found at 30% RHA replacement cement in the cement deep mixing method. In general, the decrease of UCS can be attributed to the lack of water for the pozzolanic reaction when the RHA increases above the optimum content. In addition, since the RHA is a non-plastic material, the redundant RHA can lead to decrease the soil strength. These causes are similar to the use of granulated blast furnace slag (GBFS) and ground granulated blast furnace slag (GGBFS) for the soil improvement (Sekhar et al., 2017 and Sharma and Sivapullaiah, 2016).

Regarding the effect of RHA types on UCS, as shown in Fig. 5, the UCS values of soil treated with cement and RHA1 is significantly lower than those of soil treated with cement and RHA2. This is attributed to the low silica content and the high carbon content of RHA1. Previous studies showed that the pozzolanic activity of RHA plays an important role in the enhancement of soil strength (Behak, 2017; Boateng and Skeete, 1990). Thus, the low silica content will lower the soil strength enhancement. Besides, the high carbon content in RHA can hidden the pozzolanic reaction and results in a lower increase in soil strength.

Table 3. Results of UCS and E$_{50}$ of soil treated with cement and RHA

RHA content (%)	Cement content (%)	UCS (kPa)		E$_{50}$ (kPa)	
		RHA1	RHA2	RHA1	RHA2
0	10	106.2	106.2	7662	7662
5	10	92.8	114.2	6199	7748
8	10	113	155.6	6551	9169
12	10	60.5	170.5	3952	11397
15	10	79.4	135.9	4411	8138
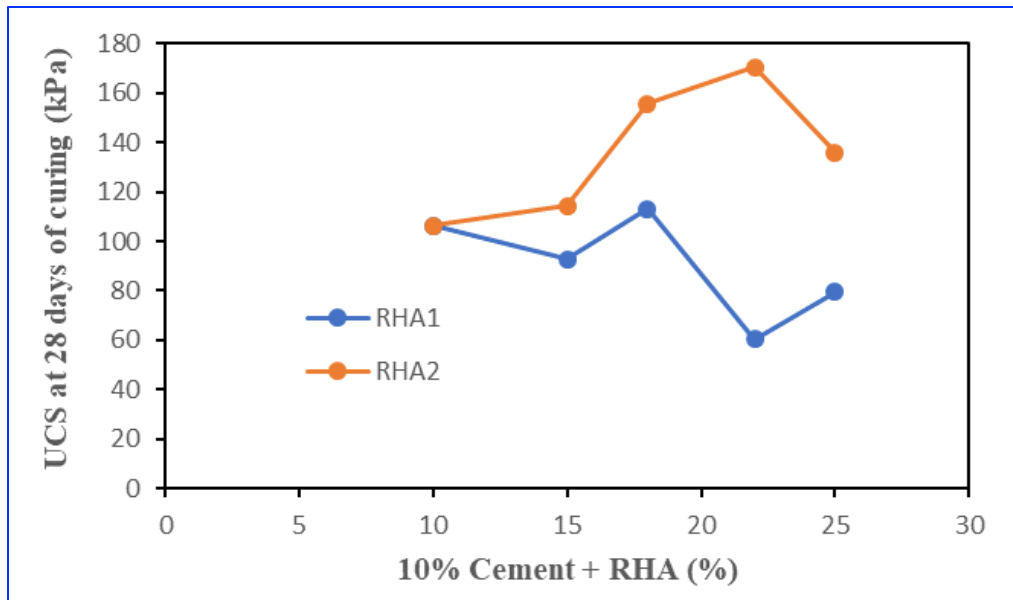
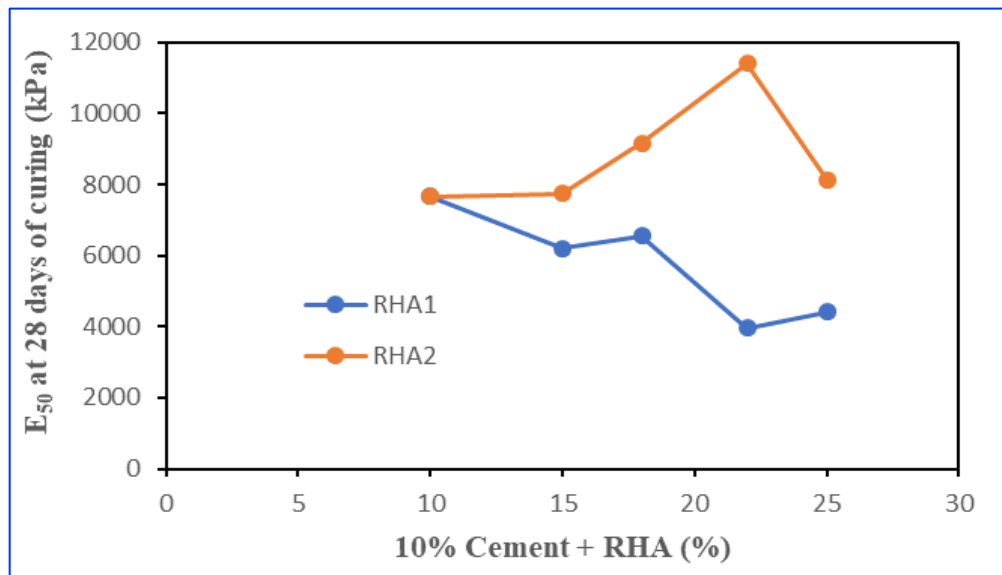**Fig. 5. Variation of UCS values of soil treated with cement and RHA**

Fig. 6. Variation of E$_{50}$ values of soil treated with cement and RHA

The variation of UCS of soil is treated with cement and different RHA contents (Fig. 6). Like the UCS values, the increase of RHA2 content leads to a significant increase in the elastic modulus (E_{50}) of treated soil. The highest value of E_{50} is also found when 12% RHA content is added to cement-admixed soil. Accordingly, the addition of 12% RHA2 can increase the E_{50} value of treated soil by 55%. By contrast, the increase of RHA1 content results in a decrease in the E_{50} of treated soil. This indicates that the RHA2 is more effective than the RHA1 in soil improvement for both UCS and E_{50} parameters. As mentioned above, the reason here is attributed to higher pozzolanic reaction activity of RHA2 compared to that of RHA1.
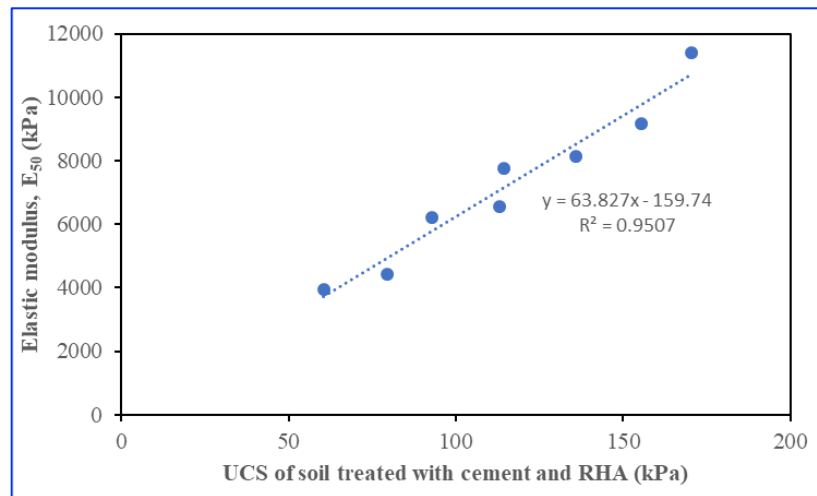

Fig. 7. Relationship between UCS and E_{50} for soil treated with cement and RHA

The relationship between UCS and E_{50} parameters for soil treated with cement and different types of RHA is plotted in Fig. 7. The E_{50} of soil is treated with cement and RHA at 28 days of curing can be estimated as 63.8UCS (coefficient of determination, R^2=0.95). This result is almost similar to that of Yoobanpot and Jamsawang (2014) while it is slightly lower than that of Jongpradist et al. (2018). Accordingly, the E_{50} of soil treated with cement and RHA can be equal to 61.2UCS (R^2=0.98) (Yoobanpot and Jamsawang, 2014) and 84.3UCS (R^2=0.91) (Jongpradist et al., 2018). For deep mixing using only cement, the E_{50} can be equal to 30UCS ÷ 300UCS (Fang et al., 2001) or 350UCS ÷ 1000UCS (Kawasaki et al., 1981). The JSG Association of Japan (1986) proposed the relationship E_{50} = 100UCS ÷ 300UCS for the jet grouting method.

CONCLUSIONS

Based on the results of this experimental investigation, the effect of RHA types on some geotechnical properties of cement-admixed soil has been clarified. Accordingly, for both types of studied RHA, the increase in RHA content leads to a reduction in the plasticity index of soil-cement

mixtures. However, the types of RHA do not affect the decrease of this index. By contrast, the soil strength of treated soil significantly depends on the types of RHA. In which, the RHA obtained from controlled burning in a furnace (RHA2) results in a significant increase of both UCS and E_{50} values of cement-admixed soil at 28 days of curing, especially with the addition of 12% RHA2, while the RHA obtained from the open fire burning (RHA1) has a little effect on the enhancement of treated soil strength. The addition of 12% RHA2 can increase the UCS and E_{50} of treated soil by more than 50% compared to those of cement-admixed soil without RHA.

ACKNOWLEDGMENTS

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