Effect of rice husk ash on physical properties of soft soil

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Abstract: Rice husk ash (RHA) is a waste material from burning rice husk which is abundant in Vietnam. The utilisation of RHA in soil improvement has been widely investigated. However, the effect of different RHA types on the physical properties of soft soil such as Atterberg limits has not been clarified yet. In this study, two types of RHA obtained from open burning and burning in a furnace will be used to investigate their effects on the physical properties of soft soil such as specific gravity, water content, and the Atterberg limits. The RHA contents from 0 to 15% by the dry weight of soil were used to mix with soft soil. The research results showed that the types of RHA have little effect on the change of water content and the Atterberg limits. Nevertheless, the RHA with low silica content (high carbon content) will result in a higher decrease in specific gravity. Regarding the change in soil particles, the addition of both RHA types can lead to an increase in the silt content of treated soil.

Keywords: rice husk ash; RHA; soft soil; burning conditions; specific gravity; water content; liquid limit; plastic limit; plasticity index.

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1 Introduction

Rice husk ash (RHA) is an agricultural-by product which is obtained from burning rice husk. In Vietnam, as estimated, the paddy production is about 44 million tons in 2018 (*Vietnam Rice Annual Report 2018 & Outlook for 2019*). After milling of paddy, about 20% of the weight of paddy is as rice husk. Since the rice husk contains a little content of protein and is very abrasive, it is not suitable for animal feed. Thus, the rice husk is often disposed of to the environment or used as fuel for drying fruits, power generation, biomass power plants. After burning, the remaining about 20% of rice husk is known as rice husk ash (RHA) (Behak, 2017; Jongpradist et al., 2018). It means that about 1.76 million tons of RHA can be produced in Vietnam every year. This huge amount of

RHA is often treated as waste and disposed of in the landfill area. RHA is porous in structure and very light (Fapohunda et al., 2017). It is difficult in transport and can cause pollution water and air due to wind flow. Therefore, an increase in utilisation of RHA will have great potential for waste management and environmental protection. There is now also an increasing trend in the utilisation of waste ash such as wood ash, mango kernel ash for soil stabilisation to reduce negative impacts on the environment (Varaprasad et al., 2020; Krishnan et al., 2020).

RHA often contains a high content of silica with above 70% which is responsible for pozzolanic reaction (Fapohunda et al., 2017). The amorphous silica in RHA will react with lime as a pozzolanic reaction to form CSH gel which can enhance the strength of soil (Boateng and Skeete, 1990; Behak, 2017). In addition, since the structure of RHA is porous and contains a layer with numerous small voids within its structure, the RHA has a high capability of water absorption (Adajar et al., 2019). This high capability can help to improve some geotechnical properties of soil such as reducing the water content, plasticity index, and swelling potential. The effectiveness of RHA in soil improvement, especially in the terms of soil strength, significantly depends on the amorphous silica content in RHA which is dependent on burning time and burning temperature (Basha et al., 2005). RHA with a high amorphous silica content is often obtained from burning rice husk in controlled conditions of time and temperature (in incinerator, furnace) whereas burning rice husk in uncontrolled conditions (biomass power plants, open fire burning) often produces the RHA with a low silica content (Cordeiro et al., 2009; Karatai et al., 2016; Behak, 2017; Liu et al., 2019). Pham and Tran (2020) indicated that the RHA with low pozzolanic activity obtained from simple burning could also improve the soil strength when RHA was used in combination with lime. Previous studies have shown that the use of RHA alone could significantly improve some physical properties of soil such as plasticity index, swelling potential (e.g., Fattah et al., 2013; Sarkar et al., 2012; Rahman et al., 2014; Akinyele et al., 2015; Aziz et al., 2015; Adajar et al., 2019). In which, the decrease in plasticity index is one of the main signs of soil improvement. However, the effect of RHA with different amorphous silica contents on Atterberg limits of treated soil has not been clarified yet. In this study, the effect of two types of RHA obtained from uncontrolled burning (open burning) and controlled burning (burning in a furnace) with different silica contents on physical properties of soft soil such as specific gravity, water content and Atterberg limits will be investigated. According to some previous studies, the maximum of RHA content used for soil improvement was often less than 15-20% (Muntohar, 2002; Okafor and Okonkwo, 2009; Yadu et al., 2011; Sarkar et al., 2012; Fattah et al., 2013; Rahman et al., 2014; Akinyele et al., 2015; Aziz et al., 2015). Thus, in this study, the RHA contents from 0 to 15% by the dry weight of soil were used to mix with the soft soil.

2 Materials and methods

2.1 Materials

2.1.1 Soil sample

The soil sample was taken at the depth of 1–2 m in Thanh Hoa Province, Vietnam. The soil sample is blackish grey, brownish grey with a soft state. The particle size distribution of soil samples is shown in Figure 1. Some physico-mechanical properties of soil sample used are listed in Table 1. According to ASTM D2487-00, the soil sample is classified into MH soil with high plasticity. The chemical compositions of soil are presented in Table 2.

Figure 1 Particle size distribution of soil sample used

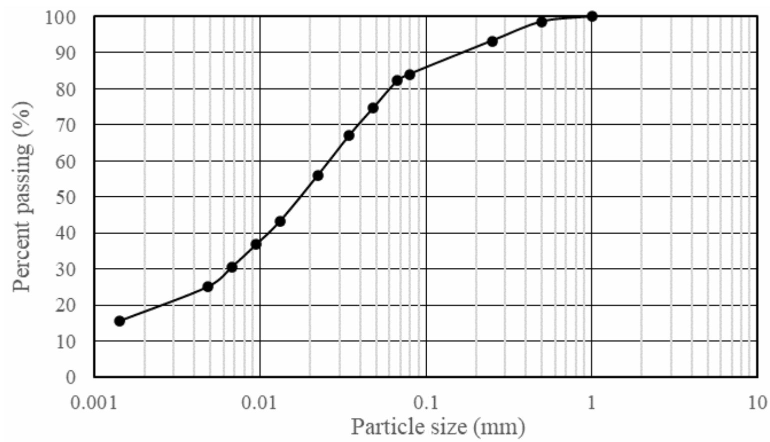


Table 1 Physico-mechanical properties of soil sample used

Index property	*Unit*	*Index value*
Natural water content	%	88.0
Wet 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
Unconfined compressive strength (UCS)	kPa	14.7
Soil classification (ASTM D2487-00)	-	MH

Table 2 Chemical compositions of soil sample used

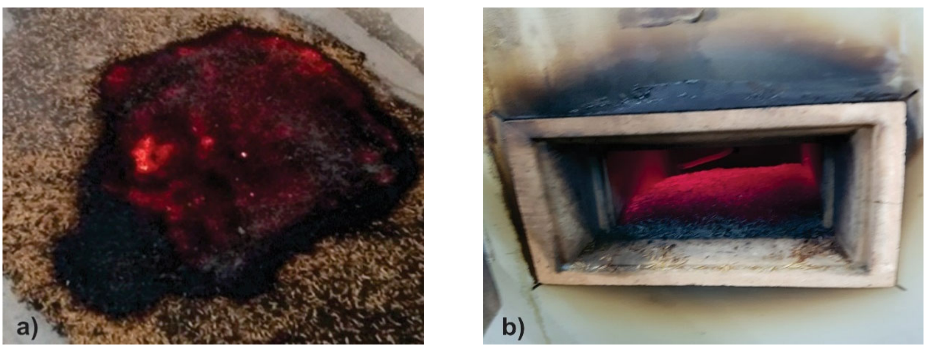
Chemical compositions (%)												
SiO_2	Fe_2O_3	Al_2O_3	TiO_2	MnO	Na_2O	K_2O	CaO	MgO	P_2O_5	SO_3	Cr_2O_3	Cl
53.64	7.62	20.10	2.16	0.06	0.18	1.49	0.56	1.69	0.07	2.39	0.05	<0.01

2.1.2 Rice husk ash

In this study, RHA obtained from no-controlled and controlled burning conditions were used. No-controlled RHA was burned in open fire for about 5–6 hours (RHA1)

[Figure 2(a)]. Controlled RHA was burned in a furnace at a temperature of about 600°C for 2 hours (RHA2) [Figure 2(b)]. Some physical properties and chemical compositions of RHA are presented in Table 3. As shown in this table, the RHA1 contains high carbon content and low silica content. The RHA2 contains 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. The colour of RHA1 is blackish grey while that of RHA2 is whitish-grey. The lighter colour of RHA shows higher content of silica and lower content of unburnt carbon (Houston, 1972). The RHA was ground and then passed through No. 40 sieve (425 µm) for this investigation. The size of RHA of less than 425 µm has been adopted in previous studies (e.g., Subrahmanyam et al., 1981; Sharma et al., 2008; Rao et al., 2012). Two types of RHA after grinding are shown in Figure 3.

Figure 2 Burning rice husk, (a) open fire burning (b) burning in a furnace (see online version for colours)



The chemical compositions of rice rusk ash in Table 3 shows that the RHA2 can be classified as a class 'F' pozzolan (ASTM C618-00), 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 as 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.

Figure 3 Two types of RHA after grinding used in this study

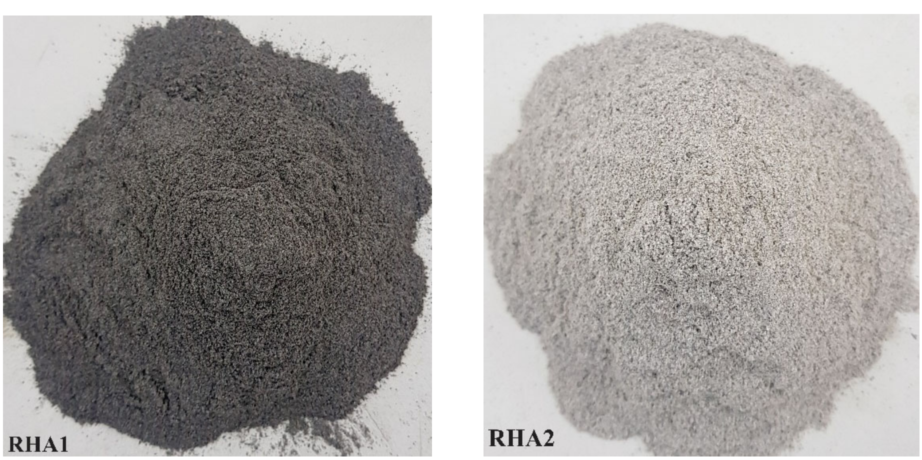


Table 3 Some physical properties and chemical compositions of RHA

Properties	*RHA1 (high carbon content)*	*RHA2 (low carbon content)*
Specific gravity	1.94	2.24
Colour	Blackish grey	Whitish grey
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

2.1.3 Sample preparation and method

RHA contents of 5, 8, 12, and 15% by dry weight of soil were mixed with the original soil. The water content of treated soil after mixing was determined in accordance with ASTM D2216-10 using the oven-drying method. The treated samples were then cured at room temperature for 24 h before testing.

The specific gravity tests were conducted in accordance with ASTM D854-02. The Atterberg limits of the original and treated soil (mixture of soil and RHA) were determined in accordance with ASTM D4318-00. The liquid limit was determined using the Casagrande method and the rolling device method was used to determine the plastic limit.

3 Test results and discussions

3.1 Water content

The water content of treated soil was determined after the soil was well mixed with different RHA contents. The results of water content are listed in Table 4. It can be seen that the increase of RHA leads to a decrease in the water content of treated soil. This is due to the high capacity for water absorption of RHA (Adajar et al., 2019). The water content of treated soil is decreased by 15.6% and 14.3% with the addition of 15% of RHA1 and RHA2 to the original soil respectively. This indicates the type of RHA has an insignificant effect on the decrease in water content.

Table 4 Effect of RHA on initial water content of treated soil

RHA content (%)	*Water content at 0 day (%)*	
	RHA1 (high carbon content)	*RHA2 (low carbon content)*
0	88.0	88.0
5	81.7	83.1
8	80.3	82.1
12	76.1	76.6
15	74.3	75.4

3.2 Specific gravity (G_s)

The variation of specific gravity of soil treated with different contents of two types of RHA is presented in Figure 3. In general, the addition of RHA to the soil will lead to a decrease in the specific gravity of treated soil. The main reason here is due to the lightweight of RHA. In this study, the specific gravity of RHA1 and RHA2 is 1.94 and 2.24 in respective which is significantly lower than that of original soil (G_s = 2.68). Thus, when RHA is mixed with soil, the overall specific gravity of treated soil will be reduced. Furthermore, the formation of flocculation and agglomeration of clay particles due to cation exchange may cause a decrease in G_s (Sakar et al., 2012). In this study, with the addition of 15% RHA, the specific gravity of treated soil decreases from 2.68 to 2.44 (decrease 8.9%) for RHA1 and from 2.68 to 2.58 (decrease 3.7%) for RHA2 (Figure 4). This indicates that the RHA with high carbon content will result in a higher decrease in the specific gravity of treated soil. The decrease in the specific gravity of treated soil obtained from this study is compared with that obtained from previous studies (Table 5). As shown in this table, the decrease in G_s of treated soil with different RHA contents varies from 3.7 to 11.9%. The decrease in the specific gravity of treated soil mainly depends on the Gs of RHA and the content of RHA used.

Figure 4 Effect of RHA on the specific gravity of treated soil (see online version for colours)

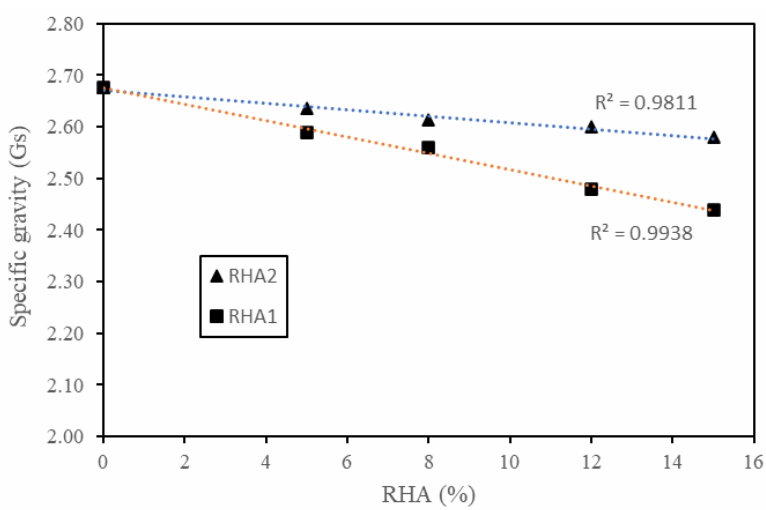


Table 5 Comparison of decrease in G_s from this study with that from previous studies

Type of soil	*G_s of soil*	*SiO_2 in RHA (%)*	*G_s of RHA*	*% RHA used*	*% G_s decrease*	*References*
Black cotton soil	2.63	-	2.04	15	8	Yadu et al. (2011)
Cohesive soil	2.65	93	2.25	12.5	7.9	Sarkar et al. (2012)
Clayey soil (Bal.)	2.69	86	2.04	9	5.9	Fattah et al. (2013)
Clayey soil (Nah.)	2.69	86	2.04	9	6.7	
Clayey soil (Nas.)	2.71	86	2.04	9	5.5	
Expansive soil (NES)	2.69	89.3	1.72	20	11.9	Aziz et al. (2015)
Expansive soil (HES)	2.72	89.3	1.72	20	10.1	
Soft soil (MH)	2.68	58.61	1.94	15	8.9	This study
	2.68	77.56	2.24	15	3.7	

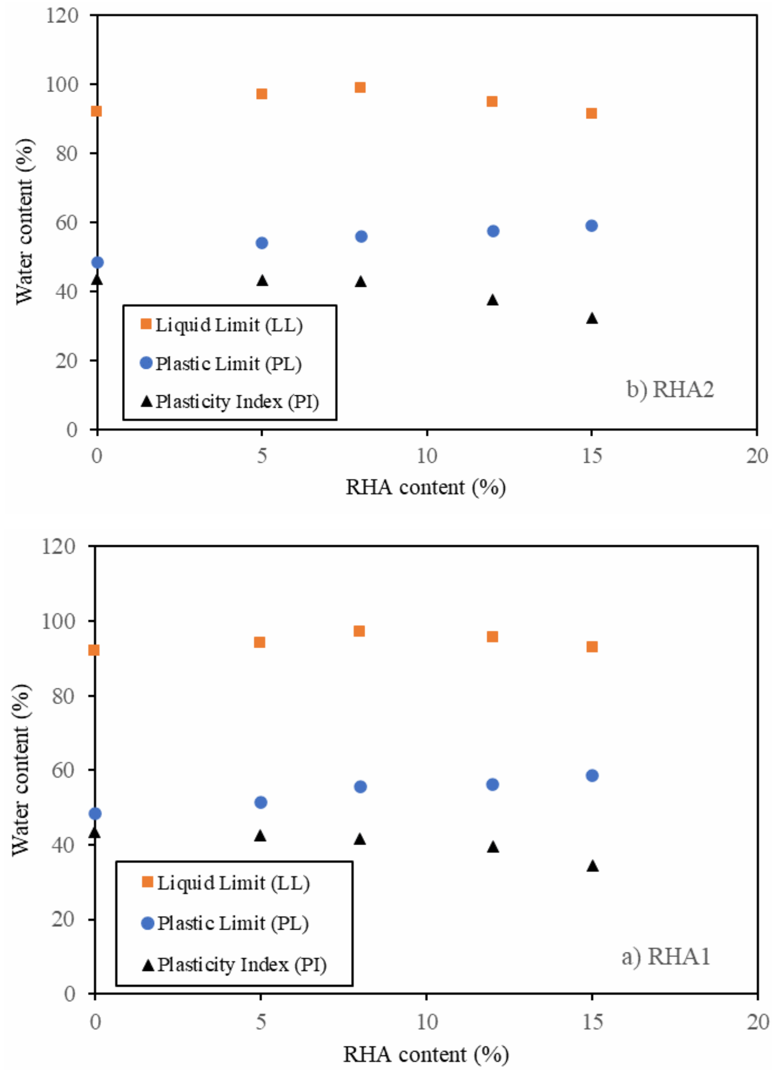
3.3 Atterberg limits

The variations of liquid limit (LL), plasticity limit (PL), and plasticity index (PI) of soil treated with different RHA contents are plotted in Figure 5. The tendency of LL, PL, and PI with increasing of RHA is similar for both types of RHA. For both types of RHA, the liquid limit of treated soil slightly increases with the addition of up to 8% RHA, then followed by a slight decrease with the increase of RHA content. The increase of LL can be attributed to the more water needed to make treated soil fluid (Okafor and Okonkwo, 2009; Sarkar et al., 2012). It is known that the liquid limit of soil significantly depends on the clay content and mineralogy. In this study, the size of RHA used was less than 425 µm which is much higher than the size of clay particles (≤2 µm). Thus, the increase of RHA above 8% will replace fine particles (clay particles) by the presence of RHA and lead to decrease liquid limit of treated soil (Rahman et al., 2014; Adajar et al., 2019). For PL of soil treated with both RHA types, there is a general increase in PL with the increase of RHA. This result is consistent with that of previous studies (Sarkar et al., 2012; Fattah et al., 2013; Akinyele et al., 2015; Adajar et al., 2019). The increase of PL can be attributed to the pozzolanic characteristics of RHA (Sarkar et al., 2012; Fattah et al., 2013).

The effect of RHA on the PI of soil treated with RHA is shown in Figure 6. As shown in this figure, the plasticity index (PI) of soil treated with both RHA types shows a decreasing trend with increasing RHA contents. The decrease of PI implies the improvement of soil. For RHA1, the PI of treated soil decreases from 43.5 to 34.5 (20.7% decrease). For RHA2, the PI of treated soil decreases from 43.5 to 32.3 (25.7% decrease). These results indicate that the types of RHA have little effect on the change of PI. For both types of RHA, the PI significantly decreases as the RHA content increases exceeding 8%. Thus, the RHA content above 8% should be used to improve the studied soil in terms of plasticity index.

The decrease in PI of treated soil with RHA obtained from this study is compared with that obtained from previous studies and listed in Table 6. It can be seen that the decrease of PI ranges from 16.7 to 66% with RHA content used from 9 to 20%. Besides, the RHA used in previous studies has a wide range of silica content (Table 6). As shown in this table, the decrease in PI of treated soil with RHA seems to be independent of silica content in RHA (types of RHA). It may depend on the characteristic of the original soil.

Figure 5 Effect of RHA on the Atterberg limits of treated soil (see online version for colours)



The test result of LL and PI of soil treated with two types of RHA from Atterberg limit tests were plotted on the Casagrande plasticity chart [Figures 7(a) and 7(b)]. This chart presents the changes in the plasticity of soil and the size of fine particles as well. As shown in these charts, all the original and treated soil samples distributed well below the A-line. The original soil was classified as MH soil with high plasticity. With the addition of a maximum 15% of RHA, the treated soil is still MH soil with high plasticity. However, it is seen that the plots moved further to the A-line. This phenomenon indicates the increase of silt content in soil treated with RHA. This tendency is seen in both types of RHA. The change of size particle of soil treated with RHA in this study contradicts that of Rahman et al. (2014). According to Rahman et al. (2014), the particle size of treated soil slightly changed to clay size characteristics. This contradiction can be attributed to the difference in the size of the RHA used.

Figure 6 Effect of RHA on the plasticity index of treated soil (see online version for colours)

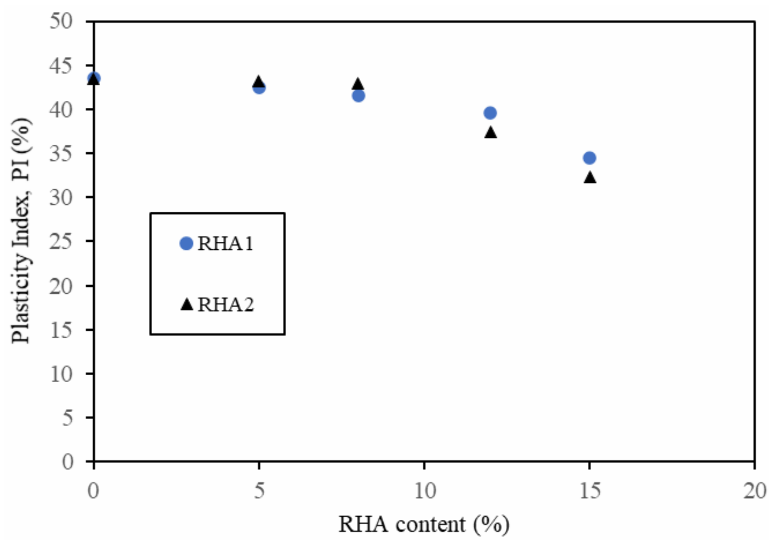
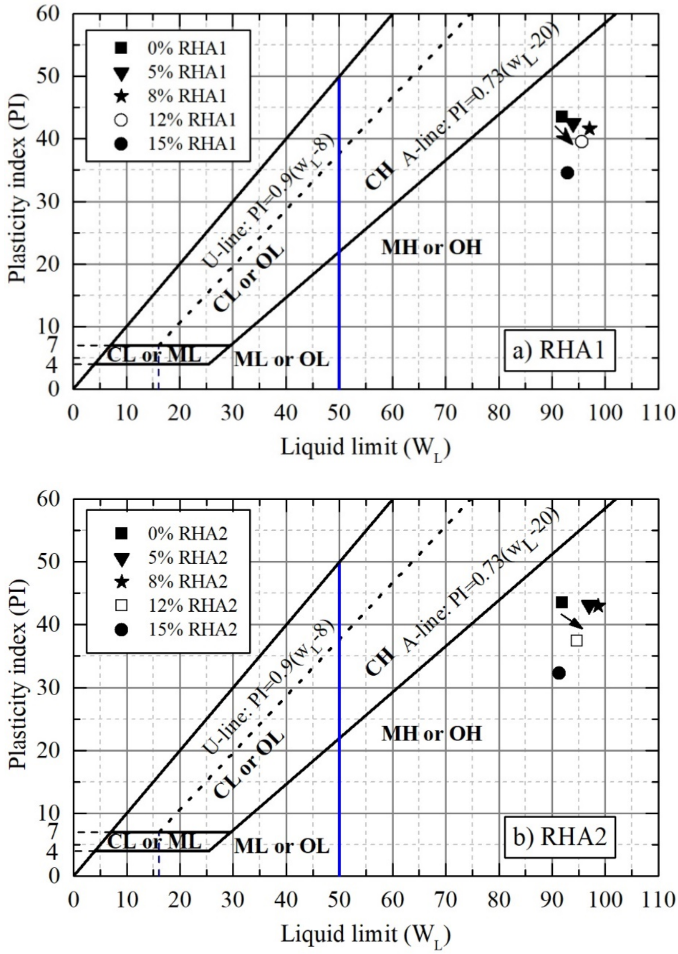


Table 6 Comparison of decrease in PI of treated soil in this study with that from previous studies

Type of soil	*PI of soil (%)*	*SiO_2 in RHA (%)*	*% RHA used*	*% PI decrease*	*References*
Expansive soil	42	89.08	12.5	40.5	Muntohar (2002)
Lateritic soil	17.1	67.3	12.5	41.3	Okafor and Okonkwo (2009)
Black cotton soil	17.0	-	15	55.9	Yadu et al. (2011)
Cohesive soil	24	93	12.5	16.7	Sarkar et al. (2012)
Clayey soil (Bal.)	24	86	9	24.3	Fattah et al. (2013)
Clayey soil (Nah.)	21	86	9	31.8	
Clayey soil (Nas.)	37	86	9	47.7	
Residual soil	37	93.1	20	27.0	Rahman et al. (2014)
Lateritic soil	21	67.3	10	49.0	Akinyele et al. (2015)
Expansive soil (HES)	33	89.3	20	39.4	Aziz et al. (2015)
Expansive soil	53	98.2	25	66.0	Adajar et al. (2019)
Soft soil (MH)	43.5	58.61 (RHA1)	15	20.7	This study
	43.5	77.56 (RHA2)	15	25.7	

Figure 7 Casagrande chart showing the original soil and soil treated with RHA (see online version for colours)



4 Conclusions

In this study, the effect of two types of RHA (open burning and burning in a furnace) on some physical properties of soft soil such as specific gravity, water content, and the Atterberg limits was extensively examined. The RHA contents from 0 to 15% were used to mix with the soft soil. Based on the analysis of test results, some conclusions are drawn as follows:

The RHA obtained from open burning (uncontrolled condition) has lower silica content, higher carbon content than that of RHA obtained from burning in a furnace (controlled condition). However, the types of these RHA have little effect on the decrease of some physical properties of treated soil such as water content, the Atterberg limits. Accordingly, with the addition of 15% of RHA1 and RHA2 to the original soil, the water content of treated soil is decreased by 15.6% and 14.3% respectively, whereas the plasticity index of treated soil is decreased by 20.7% and 25.7% respectively. This indicates that the RHA from open burning can be used to improve the plasticity index of soil. By contrast, the RHA with high carbon content significantly reduces the specific gravity of treated soil in comparison to the RHA with low carbon content. The addition of 15% of RHA1 to the original soil decreases the specific gravity of treated soil by 8.9%, while the addition of 15% of RHA2 leads to a decrease of specific gravity of only 3.7%.

The addition of RHA to the soil can change the particle size of treated soil. In this study, when the RHA content increases, the silt content in treated soil will increase. This tendency is observed in both types of RHA.

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