Lowland Technology International 2015; 17 (2): 73-82
International Association of Lowland Technology (IALT): ISSN 1344-9656

Research Paper

Effects of sugarcane bagasse ash (SCBA) on the strength and compressibility of cement stabilized peat

M.K. Abu Talib [1], N. Yasufuku [2] and R. Ishikura [3]

ARTICLE INFORMATION

Article history:

Received: 14 April, 2015
Received in revised form: 16 June, 2015
Accepted: 30 June, 2015
Publish on: September, 2015

Keywords:

Peat stabilization
Sugarcane bagasse ash
Peat strength
Peat compressibility

ABSTRACT

This research objective is to evaluate effectiveness of sugarcane bagasse ash (SCBA) inclusion in peat stabilization. To develop the optimal mix design, stabilized peat specimens were tested in unconfined compression. Energy Dispersive X-ray (EDX) and Scanning Electron Microscope (SEM) apparatus was used to examine elemental composition and microstructure. Consolidation tests were carried out in a standard Oedometer apparatus on the obtained optimum peat-cement-bagasse (PCB) mixture. It was found that stabilized peat comprising 20% partial replacement of OPC with SCBA has the maximum UCS and discovered to be about 1.2 times greater than UCS of peat-cement (PC) specimen. The UCS of optimum PCB mixture specimens increased with curing duration in water. Compared to untreated soil, SEM results for stabilized peat gave the significant pore improvement. EDX results prove that lower carbon (C) and higher calcium (Ca) fractions shows the better results of strength. There was a significant reduction of void ratio (*e*) for optimum PCB mixtures as compared to untreated peat. It was observed that preconsolidation pressure, σ'_c were increase with curing period. Results finding shows that the stabilized peat C_α/C_c ratios were decline dramatically from untreated peat which is indicating the stabilized mixture can effectively reduce the secondary compression.

1. Introduction

The vastness of peat land coverage and its occurrence close to or within population centers and existing cropped areas means some form of infrastructure development has to be carried out in these areas. In order to stimulate agriculture development for instance, basic civil engineering infrastructures such as roads are necessary (Huat et al., 2004). Peat and organic soil represent the extreme form of soft soil and subject to instability and enormous primary as well as long-term settlement even when subjected to moderate load (Jarrett, 1995). These materials are very highly compressible together with very low shear strength and hence considered to be among the worst of foundation materials in terms of its engineering properties (Dhowian and Edil, 1980; Huat et al., 2005).

[1] Graduate student, Geotechnical Engineering Laboratory, Department of Civil Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishu-ku 819-0395 Fukuoka, JAPAN, khaidir0108@gmail.com
[2] Professor, Geotechnical Engineering Laboratory, Department of Civil Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishu-ku 819-0395 Fukuoka, JAPAN, yasufuku@civil.kyushu-u.ac.jp
[3] Associate Professor, Geotechnical Engineering Laboratory, Department of Civil Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishu-ku 819-0395 Fukuoka, JAPAN, ishikura@civil.kyushu-u.ac.jp
Note: Discussion on this paper is open until December 2015

In the past few years, there are researchers who observe the ability of the cement in the stabilization of organic soil (Axelsson et al., 2002; EuroSoilStab, 2002; Hebib and Farrell, 2003; Huat et al., 2005; Ahnberg, 2006; Chen and Wang, 2006; Wong et al., 2008; Sobhan et al., 2012). It is well recognized that organic soils can retard or prevent the proper hydration of binders such as cement in binder-soil mixtures (Hebib and Farrell, 2003). As a result of high organic content and less solid particles in peat soil, cement alone is insufficient as a chemical admixture for peat stabilization. That means, the large quantity of cement is required with the purpose of acids neutralization or otherwise the process of the soil stabilization remains retarded. However, adding a large quantity of cement into the peat is absolutely an unfriendly and uneconomical solution to peat ground improvement considering the fact that the peat ground is covers a wide area, the rising cost of cement and its transportation to the site (Wong et al., 2009). Cement is responsible for about 5 % – 8 % of global carbon oxide, CO_2 emissions and expected to grow 0.8 to 1.2 % per year until may reach 4.4 billion tonnes of productions in 2050 (WBCSD, 2009).

The productions of sugarcane is world number one commodities with amount around 1.9 billion tonnes in 2013 (FAOSTAT, 2015). Bagasse is the residue left after the crushing of sugar cane for juice extraction and on average about 32 % of bagasse is produced from every tonne of sugar cane. Bagasse is burnt to generate power required for diverse activities in the factory and leave bagasse ash as a waste. Increasing concern of disposal of bagasse residual creates interest to explore the potential application of this material (Lee and Mariatti, 2008). The sugarcane industry is still seeking solutions to dispose of the wastes generated by the sugar and alcohol production processes. This ash is used as fertilizer in the plantations, but it does not have adequate mineral nutrients for this purpose (Sales and Lima, 2010). Sugar cane bagasse ash (SCBA) has also been studied as a promising pozzolanic material (Cordeiro et al., 2008; Fairbairn et al., 2010) for concrete. Nowadays, despite the increasing interest in the potential use of SCBA as a supplementary material of cement in concrete technology, there is no evidence in the current literature of its use in soil stabilization especially for organic soil.

For that reason, it could be something very useful to develop alternate binders that are environment friendly and contribute towards sustainable management by utilizes the SCBA in the stabilization of peat soil. The objective of this research works is to evaluate effectiveness of SCBA inclusion in peat stabilization especially on its strength and deformation behavior.

2. Experimental studies

Peat soil, Ordinary Portland Cement (OPC), calcium chloride ($CaCl_2$), silica sand and Sugarcane Bagasse Ash (SCBA) had been used in this study. Peat samples were obtained from Sapporo in the Hokkaido region, Japan. The SCBA samples were brought from Shinko Sugar Industry Co., Ltd., Kagoshima prefecture in Kyushu, Japan. Besides OPC as main binder and $CaCl_2$ as cement accelerator, well graded silica sand so called K7 type was prepared as a filler to increase the solid particles and enhance the filling effect of the stabilized peat. The entire laboratory test regulation and standards that had been implemented in this study was adopted from American Society for Testing and Materials (ASTM, 2005) standards.

The unconfined compressive strength (UCS) tests were conducted at all samples with the aim to clarify the stabilized peat strength improvement. In order to understand the chemical reaction mechanism of mixture strengthening, an Energy Dispersive X-ray (EDX) had been conducted on untreated and stabilized peat. The EDX results are expected will provide chemical evidence on the existence of calcium, silica and alumina which is the major elements of cementation products in the stabilized peat. In addition to such chemical characterization, the scanning electron micrographs (SEM) are conducted to give micro visual evidence on cementation and void enhancement of the stabilized soil. Consolidation tests were carried out in the standard Oedometer apparatus on the optimum peat-cement-bagasse (PCB) mixtures that obtained from UCS test. The sizes of specimens were 60 mm in diameter and 30 mm in height. The Oedometer tests comprised seven incremental load stages and each load stage lasted 24 hours. An initial stress of 10 kPa was applied and the stress was increased in steps at the end of each load stage using a load increment ratio of unity until a final stress of 640 kPa had been applied. The whole mix designs of stabilized peat for laboratory testing are shown in Table 1. The mix designs of stabilized peat were formulated in term of binder composition and dosage. Each binder dosage was determined based on the bulk density of peat at its average natural water content. In making each admixture, 300 kg/m^3 of OPC dosage together with 3 % of $CaCl_2$ and 500 kg/m^3 of K7 were mixed with untreated peat by using a laboratory mixer at approximately 10 minutes. Next, the stabilized specimens were place into the mould by filling and tamping in about five equal layers. Each cylinder mould has a size of 60 mm internal diameter and 300 mm height. The samples then immersed in water for curing at identified duration under 20 kPa initial pressure by using

Table 1. Laboratory mix designs.

No. test	Type of test	Description of test purpose	Curing duration (days)	Binder compositions @ acronym
1	UCS, EDX, SEM	To investigate the effect of binder composition on the tested specimens	7	100% [1]OPC @[3]PC 95%OPC:5%[2]SCBA @[4]PCB5 90%OPC:10%SCBA @ PCB10 85%OPC:15%SCBA @ PCB15 80%OPC:20%SCBA @ PCB20 75%OPC:25%SCBA @ PCB25 70%OPC:30%SCBA @ PCB30 65%OPC:35%SCBA @ PCB35
2	UCS	To investigate the effects curing duration on the best test specimens	7, 14, 21, 28, 60	The optimum binder compositions from test (1)
3	Consolidation test	To investigate the magnitude and rate of consolidation of the best test specimens on various curing period	7, 28, 60	

[1]OPC *Ordinary Portland Cement* [3]PC *Peat-cement mixtures*
[2]SCBA *Sugarcane Bagasse Ash* [4]PCB *Peat-cement-bagasse ash mixtures*

Table 2. Hokkaido peat soil properties.

Peat soil properties	Results	Published data
Natural water content, %	580	115-1570
Ash content, %	16.79	2-80
Organic content , %	83.21	20-98
Bulk unit weight (kN/m^3)	10.57	7.1-19.7
Specific gravity, G_s	1.67	1.04-2.63
Fiber content, %	43	42-86.9
Acidity ,pH	5.46	-
Liquid Limit, %	375	-
Void ratio, e_o	9.65	2-21
Compression Index, C_c	4.89	0.3-14
Preconsolidation pressure, σ'_c (kPa)	25	-
Unconfined compressive strength, q_u (kPa)	13.6	5-40

air pressure to simulate the surcharge pressure on the stabilized soil site. After curing, the cylinder tube is removed and the test specimen is cut to the required size for testing. Towards the degree of improvement evaluation, the established parameters of the stabilized soil should be compared to those of untreated peat.

3. Results and discussions

3.1 Materials properties

The average values of basic properties of the untreated peat and the percentages of oxide compounds of the materials were reveals in Table 2 and Table 3 respectively. In order to ensure the reliability of results in Table 2, the basic properties ranges for typical Hokkaido peat were collected from published data (Noto, 1991; Hamamoto et al., 2010; Hayashi et al., 2011) and had been used for guidance purpose. Moisture or natural water content is determined by drying a peat sample at 105°C about 24 hour. Ash content is determined by igniting the oven-dried sample in a muffle furnace at 440°C about 7 hours (until no change in mass). The ash content is expressed as a percentage of the mass of the oven-dried sample. Organic matter is determined by subtracting percent ash content from one hundred. Fiber content was calculated by soaking peat sample in a dispersing agent (5 % sodium hexametaphosphate) for approximately 15 h. The material is then washed through a 100-mesh (150 μm) sieve by application of a gentle flow of tap water. The fibrous material left on the sieve is oven-dried (at 105°C) until a constant mass is achieved.
The mass of fiber is expressed as a percentage of the oven-dried mass of the original sample.

In this study, it can be seen that the peat has fiber content between 33 % and 67 %, ash content exceed 15 % and pH value at 5.46. Hence, this peat can be classified as hemic peat with high ash content and moderate acidic (ASTM, 2005). With the high water content, liquid limit, void ratio, compression index accompanied by low shear strength, the studied peat demonstrated the high compressibility and instability characteristics. The unconfined compressive strength (q_u) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test (ASTM, 2000). In this study, the unconfined compressive strength is taken as the maximum load attained per unit area or the load per unit area at 15 % axial strain, whichever occurs first during the performance of a test. For untreated peat, the specimen was prepared in the mould size of 50 mm diameter and 100 mm length in three layers. Each layer was subjected 10 full thumb pressures at about 10 seconds (Axelsson et al., 2002). The sample then trimmed and tested under vertical axial load at constant rate of strain of 1 mm min^{-1}. The result shows the peak was not obtained until 20% of axial strains. Hence, the max value of UCS was taken at 15 % of strain which is equal to 13.6 kPa. Compression index, C_c was obtained from the variation of the void ratio e, Δe as a function of the change of effective stress, σ'_v plotted in the logarithmic scale, $C_c = \Delta e/(\Delta \log \sigma'_v)$ while preconsolidsation pressure, σ'_c was acquired by using Casagrande's graphical method.

It is noticeable that the peat has very low contents of pozzolanic minerals (sum of SiO_2, Al_2O_3 and Fe_2O_3) with only 8.4 %. The OPC is predominantly characterized by CaO_2, SiO_2, Al_2O_3 and Fe_2O_3. and this finding agree with Isaia et al. (2003). With very high content of SiO_2, it can be confirmed that quartz is the main mineral in the K7 silica sand. For SCBA, it was found that the summation of the crucial pozzolanic oxide compounds (SiO_2, Al_2O_3 and Fe_2O_3) is 74.48 % of the total oxide compounds. These results indicate the suitability of SCBA as a pozzolan since the amount of such oxide compounds exceeds 70 % as recommended by ASTM C618 (2003) Standard. This standards is widely used in determine the required specification for coal fly ash and natural pozzolan.

The particle size distribution of the peat and other materials are tabulated in Fig. 1. The particle size distribution curves for the soils were obtained by dry sieve analysis. In addition to the normal sieve test method, the finer fraction was analyzed using a laser diffraction method (SALD). As can be seen, Hokkaido peat consists of 90 % of the soil that finer than 4.75mm, and about 2 % is finer than 75μm. Most of K7 particles sizes are 0.05 to 0.3 mm in range while the size of SCBA particles consists more 80 % finer than 0.045mm. According to ASTM C618 (2003) Standard, volume fraction of more than 66 % of particles smaller than 45 μm is required for a pozzolanic material.

Table 3. Oxide compounds of peat and materials.

Oxide Compound (%)	Peat	OPC	Sand (K7)	SCBA
CO_2	86.78	-	-	-
Na_2O	0.32	0.82	-	-
MgO	0.38	1.26	0.18	1.69
P_2O_5	1.94	2.69	0.42	3.86
SO_3	0.22	6.55	0.74	3.81
K_2O	0.64	0.84	0.77	13.77
CaO	0.65	65.40	0.23	1.84
TiO_2	0.62	-	-	0.55
Al_2O_3	1.5	6.60	3.49	17.14
SiO_2	5.48	10.26	93.52	51.61
Fe_2O_3	1.46	5.57	0.65	5.73
Al_2O_3+SiO_2+Fe_2O_3	8.4			74.5

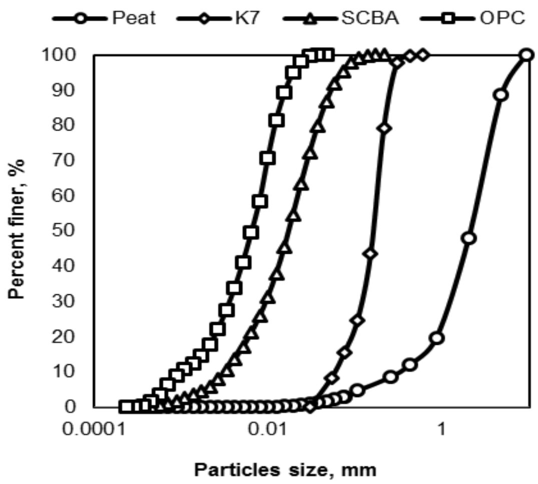

Fig. 1. Particle size distribution of peat and materials.

3.2 Effect of partial replacement of OPC with SCBA on the strength characteristic

Fig. 2(a) shows the experimental results of the effect of SCBA percentage replacement on the UCS of the stabilized peat. An optimal UCS of the stabilized soil was evaluated based on the results of unconfined compression tests on the specimens of stabilized peat with partial replacement of the cement with SCBA that varies from 5 % to 35 % as shown in Table 1. It can be detected that the test specimen with 20 % partial replacement of OPC with SCBA (PCB20) has the highest UCS of 387 kPa and was discovered to be about 1.2 times greater than UCS of PC specimen (q_{100}). ASTM D4609 (2001) can be used for evaluate an effectiveness of admixtures for soil stabilization. According to this standard, the increment in UCS of 345 kPa (adopted as minimum UCS target in this study) or more must be achieved for a treatment to be considered effective.

The main reasons why PC mixture gave lower strength than optimum mixture (PCB20) are because peat soil consists of high organic content and less solid particles as showing in Table 3. Organic soils can retard or prevent the proper hydration of binders such as cement in binder-soil mixtures and become insufficient to provide the required function for peat stabilization. Matched to clay and silt, peat has a considerably lower content of clay particles that can enter into secondary pozzolanic reactions (Janz and Johansson, 2002; Hebib and Farrell, 2003). The combination of humic acid with calcium ions produced in cement hydration makes it difficult for the calcium crystallization, which is responsible for the increase of peat soil-cement mixture strength to take place (Chen and Wang, 2006).

Generally, chemical reactions between cement and pozzolan with water are denoted in Eqs. (1) and (2). Calcium silicate hydrates (CSH) or also known as tobermorite gels together with calcium hydroxide (CH) are formed when cement reacts with water (H) in peat. The CSH act as adhesive that binds and grasp the soil particles together. Nevertheless, humic acid in peat reacts with calcium ion to form insoluble calcium humid acid. These conditions make the secondary pozzolanic reaction between CH and the peat is inhibited and this renders a low strength gain in the soil-cement mixture.

$$C_3S + H = CSH + CH \tag{1}$$

$$CH + \text{Pozzolan} + H = CSH \text{ or / and } CASH \tag{2}$$

The fact that the test specimen of PCB20 has the highest UCS may be explained by a condition whereby it has achieved an optimal effect of hydration reaction. By means of the inclusion of pozzolan such as SCBA in the soil-cement mixture, hydration of cement is accelerated when the pozzolan reacts with calcium hydroxide and water to form more secondary tobermorite gels along with calcium alumina silicate hydrates (CASH) as shown in Eq. (2). This is probable because the pozzolan which contains extra silica and alumina that activated by cement is able to counterbalance the acid and create an alkaline atmosphere that boosts the secondary pozzolanic reaction within the cemented soil. Additional

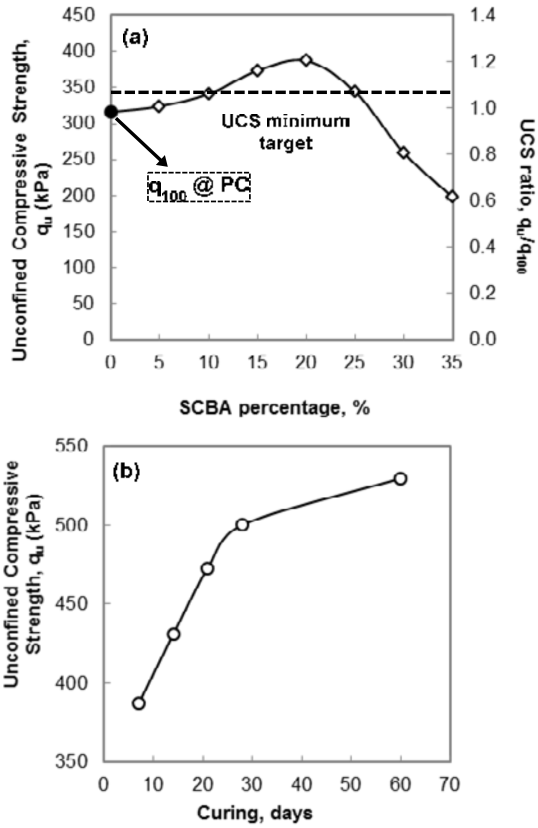

Fig. 2. (a) Effect of SCBA percentage replacement on the UCS of the stabilized peat; **(b)** Effect of optimum PCB mixture on the UCS at various curing durations.

CSH and CASH densify the stabilized peat, thereby further enhancing its strength (Wong et al., 2009).

It can be observed from Fig. 2(b) that the UCS of optimum PCB mixture specimens (PCB20) increased while increasing the duration of curing in water. When the surcharge of 20 kPa was applied, the UCS of test specimens increased progressively from 387 to 431, 473, 501 and 529 kPa at the respective curing time in water of 7, 14, 21, 28 and 60 days. It is evident from the findings that the duration of curing in water influenced the UCS of test specimens. The rate of the UCS development was very rapid within 7 days of curing duration, after which between 28 and 60 days of curing time, it reached a state of transition in which the UCS increase began to slow down. A drastic increase in the unconfined compressive strength at 7 days of curing was mainly attributed to a combination of filler effect of both silica sand and SCBA, hydration reaction of the cement, and pozzolanic activity of SCBA. Pozzolanic reactions depend on calcium hydroxide released by the hydration reactions of calcium silicates. Frequently, the pozzolanic effect depends not only on the pozzolanic reaction but also on the physical or filler effect of the smaller particles in the mixture (Isaia et al., 2003). The positive result indicates that the optimal mix design can be effectively applied to stabilize the peat in such a way that the fine particles the fine particles of pozzolan fill up the pore spaces of the cemented soil, thus closely packing, reinforcing and strengthening its matrix as the hydration and pozzolanic products are formed during cement hydrolysis (Wong et al., 2013b).

Figure 3 depicts the results of SEM test on untreated and some stabilized peat samples. Obvious change had seen and occurred when comparing the SEM results of stabilized peat with the untreated peat. It has been observed that the untreated peat contains coarse organic particles and fibers in a loose condition. They were organized arbitrarily without significant microstructural orientation. The organic coarse particles were typically hollow and spongy. Due to spongy nature of organic coarse particles, untreated peat is highly compressible and has a high water holding capacity when fully saturated (Wong et al., 2013a). Minor void spaces can be detected in the photomicrographs of stabilized peats mixtures (PC, PCB20 and PCB30). Compared to PC and PCB30 mixtures, a PCB20 mixture (optimum mixture) gave the significant pore improvement that can be perceived in the photomicrograph of the stabilized peat. It can be stated that the stabilized soil is characterized by a well cemented soil medium with tiny pore spaces within it as a result of the pozzolanic activity of SCBA.

The summary of vital oxide compound percentages of unstabilized and stabilized peat from EDX test are shown in Fig. 4. From this results, it is clearly depicts that lower carbon (C) and higher calcium (Ca) fractions shows the better results of strength (UCS). The essential pozzolanic mineral (Silica and Alumina) display the high values for stabilized peat because of SCBA and K7 presence. It also denote that there is more pozzolan minerals was involved in the secondary pozzolan reaction that boosted by more CH. At mix binder C70B30, carbon illustrates the increment value while the calcium compounds were declining. These occurrences happened because when insufficient cement is added, hydration and pozzolanic reaction become lower and effective neutralization of humid acids within the soil is not achieved. This is due to the limited formation of primary cementation products to bind the soil because the soil organic matter tends to retain the calcium ions produced from cement hydrolysis, resulting in a limited amount of CH that could react with SiO_2 and alumina Al_2O_3 of SCBA to yield secondary pozzolanic products during the pozzolanic reaction.

3.3 Effect of partial replacement of OPC with SCBA on the deformation characteristic

The void ratio, *e* versus effective vertical stress, σ'_v for untreated and stabilized peat (optimum mixture, PCB20) are shown in Fig. 5. It revealed from the Fig. 5

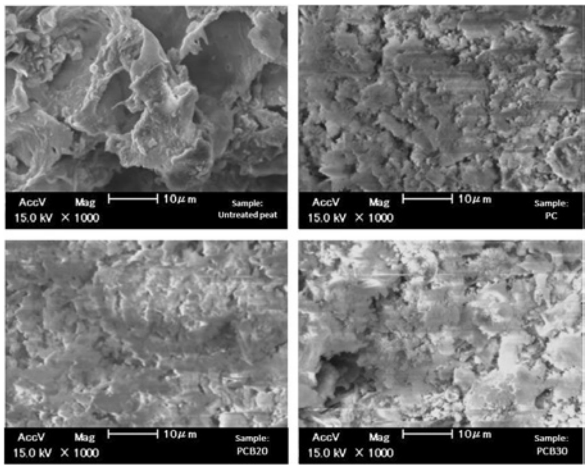

Fig. 3. Scanning Electron Microscope (SEM) on untreated (above left) and stabilized peat (PC: above right, PCB20: below left, PCB30: below right).

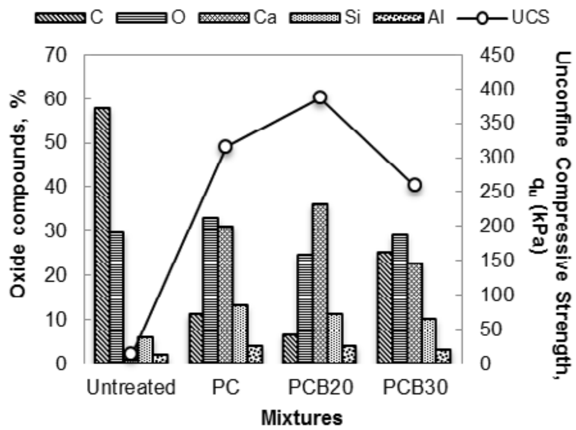

Fig. 4. Summary of crucial oxide compound percentages of untreated and stabilized peat from EDX test.

(a) that untreated peat demonstrated the high *e* and coefficient of compression, C_c with about 9 and 4.9 respectively. This is because of plant matters that constitute peat particles are light and hold a considerable amount of water. Peat grains, plates, fibers, or elements are light because the specific gravity of organic matter is relatively small and the particles are porous. As a consequence of high in *e*, peat deposits display high values of compression index, C_c (Mesri et al., 1997).

Fig. 5(b) displays that there was a significant reduction of *e* in the stabilized peats as compared to that of the untreated one. However, the *e* of stabilized peat seems shows the slow lessening with curing age. Stabilization of peat would significantly reduce the void ratio and consequently its permeability but the duration of stabilization does not seem to affect its permeability to a large extent (Wong et al., 2009). Euro Soil Stab (2002) reported that permeability tests on peat with different

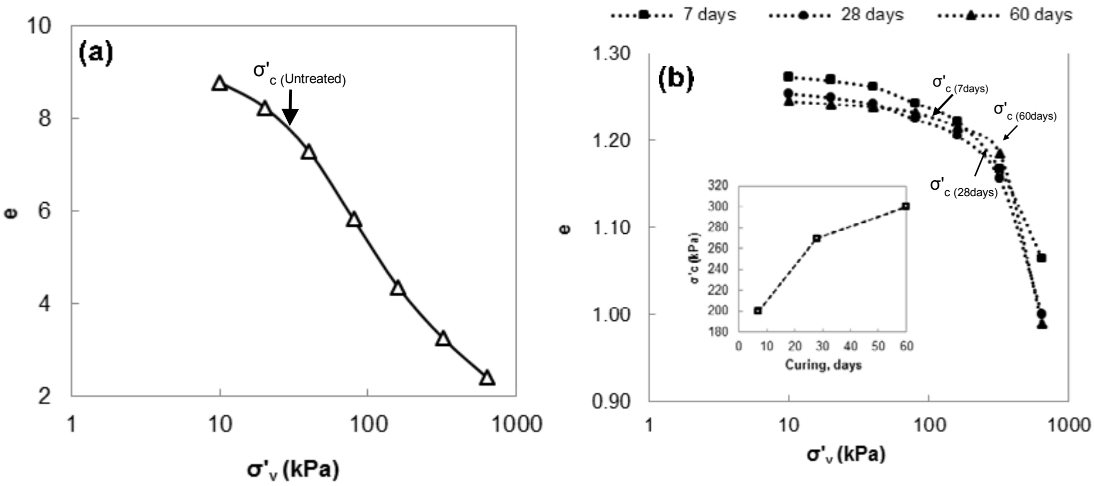

Fig. 5. Void ratio (e) versus effective vertical stress (σ'_v) for; **(a)** untreated peat; **(b)** PCB20 mixture at 7, 28 and 60 days of curing.

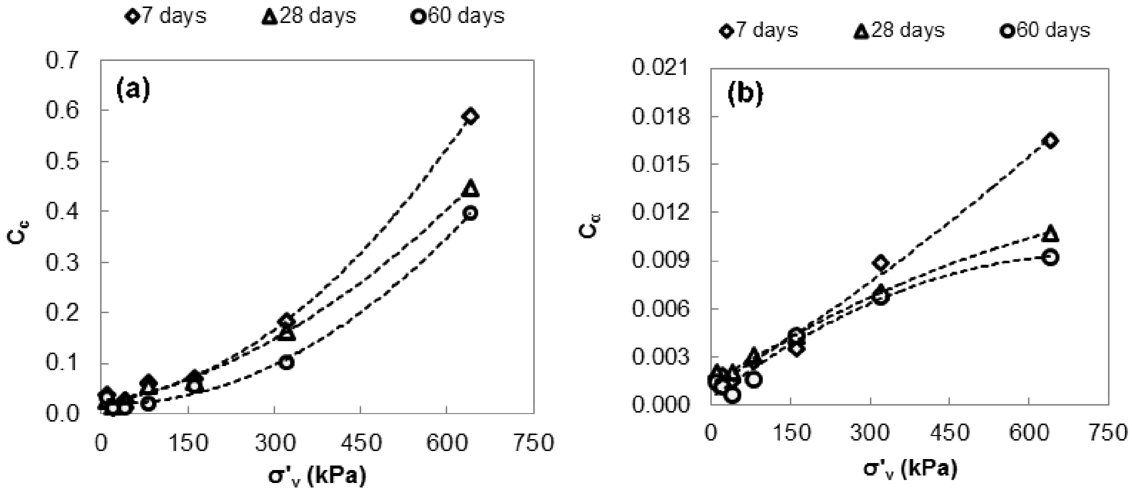

Fig. 6. The variation of compression index, C_c and coefficient of secondary compression, C_α with applied effective stress at different curing times on PCB20 mixture.

binders showed that the permeability of stabilized peat was between 10^{-9} to 10^{-8} m/s after 28 and 180 days respectively. The permeability of stabilized peat was also found to be affected by the preloading. Stabilized peat subjected to preloading tends to yield lower permeability as compared to that without preloading (Hebib and Farrell, 2003). This figure also point out that the important effect of treatment on the compression behavior is the increase in the preconsolidation pressure, σ'_c with curing age. The σ'_c increased from 25 kPa (untreated peat) to about 250 kPa, 275 kPa and 290 kPa at 7, 28 and 60 days respectively. This increase in σ'_c is in agreement with the increase in strength with time recorded from the UCS results (Fig. 2b). As a result of the development of this σ'_c, the compression curve of the treated soil is shifted to higher effective stress. Moreover, the compressibility of the stabilized peat measured in the overconsolidated area also shows a decrease with increasing curing duration. These two effects are an indication of the effectiveness of the treatment in reducing settlements (Bobet et al., 2011).

The variation of C_c and C_α with applied effective stress at different curing times is shown in Fig. 6 (a) and (b) respectively. It shown the value of C_c and C_α was relatively low at low effective stresses, however it increased as preconsolidation pressure was approached and continuous to rise after beyond these pressure. Significant increase in C_α occurs after yielding for the cement-stabilized peat discovered that creep could be associated with a structural breakdown (Hebib and Farrell, 2003). Since the standard oedometer apparatus that had been used in this study cannot determine the dissipation of water during consolidation, it assumes that secondary compression started 4 hours after loading. This assumption approach adopted from previous research conducted by Hebib and Farrel (2003) and Duraisamy (2008). Therefore, $C_\alpha = \Delta e / (\Delta \log t)$ was determined from the slope of the *e* – log t curves 4–24 h after a load increment was applied.

Figure 7 shows the variation of compression index ratio, C_α/C_c for untreated and stabilized peat at different curing times. The most detailed measurements and existing reliable data suggest a range of $C_\alpha/C_c = 0.06 \pm 0.01$ for natural peat deposits (Mesri et al., 1997). Lower ratio of C_α/C_c indicates the lesser compressibility of soils. Compared to untreated Hokkaido peat which contributed the ratio of C_α/C_c about 0.066, stabilized peat at 7, 28 and 2 month of curing in water gave better ratio with 0.0304, 0.0277 and 0.0271 individually. For that reason, it can be said that less creep settlements develop when the peat is stabilized with optimum PCB mixtures. The ratio C_α/C_c was perceived slightly higher at 7 and 28 days compared to 60 days. This could be explained by the fact that the soil is still experiencing chemical reaction between this duration of curing. In other words, the longer duration of curing of the stabilized peat in water, the lesser was its ratio of C_α/C_c which is indicating that it was less compressible.

The C_α/C_c ratios were plotted against curing period and UCS in Fig. 7 (b) and (c). As the C_α/C_c ratio decreases, the soil engineering behavior is known to shift from that of peaty or organic soils to inorganic soils and finally to a granular material (Mesri et al., 1994; Hwang, 2005; Bobet et al., 2011; Sobhan et al., 2012). It is found that the stabilized peat C_α/C_c ratios reached to granular soil materials at a curing age of 1 week, 1 month and 2 month respectively. With curing duration from 28 days to 60 days, small noticeable improvements were observed and the pattern was similar to gained UCS results. These results are encouraging, since the compression behavior of organic soils appears to be fundamentally changed to that of granular soil, which is considered to be an excellent foundation material by the geotechnical and pavement engineers (Sobhan et al., 2012).

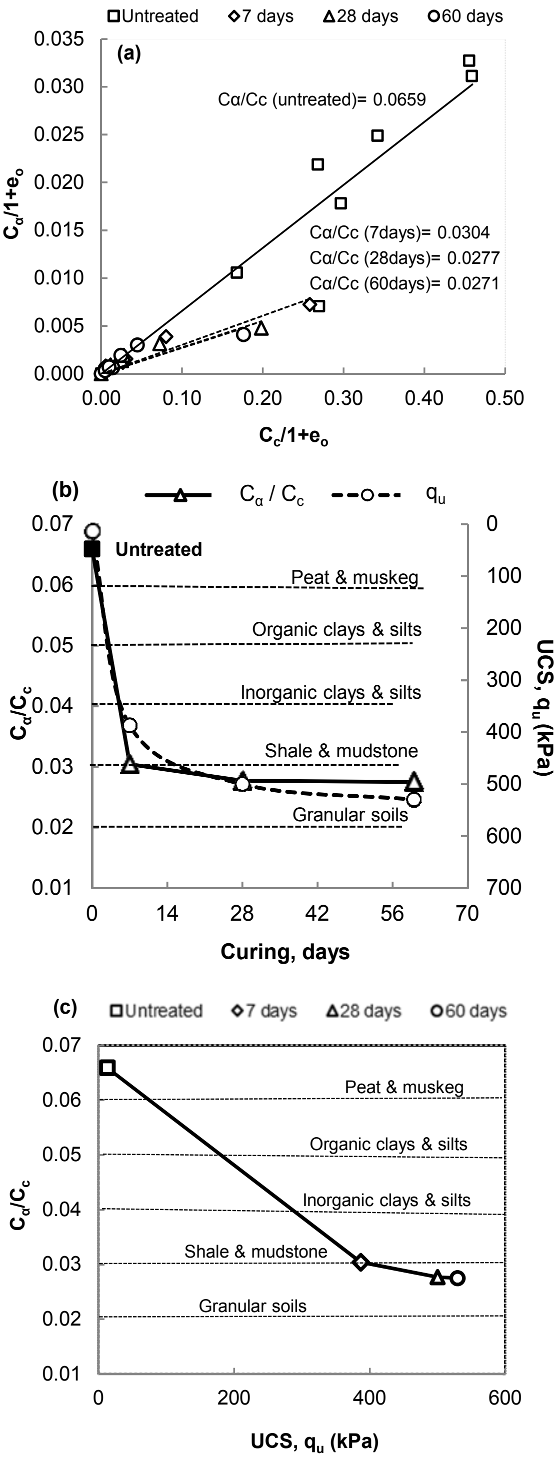

Fig. 7. The variation of compression index ratio, C_α/C_c untreated and PCB20 mixture at different curing times.

4. Conclusions

Utilization of sugarcane bagasse ash (SCBA) as supplementary material of cement on the stabilized peat has been examined. It can be summarized from the experimental results that SCBA has made a significant influence on the mechanical properties of the stabilized peat. Based on the outcomes of the laboratory analysis, the following concluding comments are made.

i. It was observed that the test specimen with 20% partial replacement of OPC with SCBA has the highest UCS of 387 kPa and was discovered to be about 1.2 times greater than UCS of PC specimen (q_{100}). The UCS of optimum PCB mixture specimens (PCB20) increased from 387 to 501 and 529 kPa at the respective curing time in water of 7, 28 and 60 days.

ii. Compared to untreated soil, SEM results for stabilized peat gave the significant pore improvement that can be perceived in the photomicrograph and it can be stated that the stabilized soil is characterized by a well cemented soil medium with small pore spaces within it as a result of the pozzolanic activity of SCBA.

iii. EDX results prove that lower carbon (C) and higher calcium (Ca) fractions shows the better results of strength (UCS). The essential pozzolanic mineral (silica and alumina) display the high values for-stabilized peat which indicate that there is more pozzolan minerals was involved in the secondary pozzolan reaction that boosted by more CH.

iv. There was a significant reduction of void ratio, *e* for optimum PCB mixtures as compared to that of the untreated one. However, the *e* of this stabilized peat seems shows the slow decreasing with curing age. The essential effect of treatment on the compression.

v. The value of C_c and C_α was relatively low at small effective stresses, however it increased as preconsolidation pressure, σ'_c was approached and continuous to rise after beyond these pressure. Compared to untreated Hokkaido peat which contributed the ratio of C_α/C_c about 0.066, stabilized peat at 7, 28 and 2 month of curing in water gave better ratio with 0.0304, 0.0277 and 0.0271 individually. Results finding shows that the stabilized peat C_α/C_c ratios were decline dramatically from untreated peat which is indicating the stabilized mixture can effectively reduce the secondary compression.

Overall, it is suggested that the obtained optimum mix design can be applied to stabilized shallow peat layer in order to support road embankment. The encouraging results from this research work is attributed to the activities among the cement hydration, the pozzolanic reaction and filler effect of SCBA that complemented with silica sand in the stabilized peat.

Acknowledgement

The authors would like to thank Mr. Michio Nakashima for technical assistance and all members of Kyushu University Geotechnical Laboratory Group for their supports. We also thank the Shinko Sugar Industry Co. Ltd providing the sugarcane bagasse ash.

References

Ahnberg, H., 2006. Strength of stabilised soils-A laboratory study on clays and organic soils stabilised with different types of binder, Swedish deep stabilization Research Centre, Report 16: pp 80 (English translation).

ASTM, 2000. D2166-00 Standard test method for unconfined compressive strength of cohesive soil. American Society for Testing and Materials Standards, Pennsylvania, USA, **4** (8): pp 6.

ASTM, 2001. D4609-01 Standard guide for evaluating effectiveness of admixtures for soil stabilization. American Society for Testing and Materials Standards, Pennsylvania, USA, **4** (8): pp 5.

ASTM, 2003. C618-03 Standard specification for fly ash and raw or calcium natural pozzolanas for use in concrete. American Society for Testing and Materials Standards, Pennsylvania, USA, **4** (8): pp 3.

ASTM, 2005. American society of testing materials. Annual Book of ASTM Standards, Soil and Rock (I): D 420-D 5611, **4** (8): pp 1492.

Axelsson, K., Johansson, S.E. and Anderson, R., 2002. Stabilization of organic soils by cement and pozzolanic reactions-Feasibility study. Swedish deep stabilization Research Centre, Report 3: pp 52 (English translation).

Bobet, A., Hwang, J.H., Johnston, C.T. and Santagata, M., 2011. One-dimensional consolidation behavior of cement-treated organic soil. Can. Geotech. Journal, **48** (7): 1100-1115.

Chen, H. and Wang, Q., 2006. The behaviour of organic matter in the process of soft soil stabilization using cement. Bulletin of Engineering Geology and the Environment, **65** (4): 445-448.

Cordeiro, G.C., Toledo, R.D., Tavares, L.M. and Fairbairn, E.M.R., 2008. Pozzolanic activity and filler effect of sugar cane bagasse ash in portland cement and lime mortars. Cement & Concrete Composites, **30** (5): 410-418.

Dhowian, A.W. and Edil, T.B., 1980. Consolidation behavior of peats. Geotech. Testing Journal, **3** (3): 105-114.

Duraisamy, Y., Huat, B.K., Muniandy, R. and Aziz, A.A., 2008. Compressibility behavior of fibrous peat reinforced with cement columns. ICCBT-E (09):93-110.

EuroSoilStab, 2002. Development of design and construction methods to stabilize soft organic soils. Design guide soft soil stabilization. CT97-0351. Project No. BE 96-3177, Industrial & Materials TechnologiesProgramme (Brite-EuRam III), European Commission: 94 pages.

Fairbairn, E.M.R. et al., 2010. Cement replacement by sugarcane bagasse ash: CO2 emissions reduction and potential for carbon credits. J. Environ. Management, **91**: 1864-1871.

FAOSTAT, 2015. Food and agricultural commodities production. Food and Agriculture Organization of the United Nations: http://faostat3.fao.org/browse/rankings/commodities_by_regions/E.

Hamamoto, S., Dissanayaka, S., Kawamoto, K. and Komatsu, T., 2010. Effects of moisture content and shrinkage on soil-thermal properties for peat soils in Japan. Intl. Conf. on Sustainable Built Environment (ICSBE-2010) Kandy, Sri Lanka, 13-14 December 2010: 53-57.

Hayashi, H., Nishimoto, S. and Takahashi, M., 2011. Field Performance of PVD combined with reinforced embankment on peaty ground. Soils and Foundation, Japanese Geotechnical Society, February 2011, **51** (1): 191-201.

Hebib, S. and Farrell, E.R., 2003. Some experiences on the stabilization of Irish peats. Can. Geotech. Journal, **40** (1): 107-120.

Huat, B.K., Maail, S. and Mohamed, T.A., 2005. Effect of chemical admixtures on the engineering properties of tropical peat soils. American Journal of Applied Sciences, **2** (7): 1113-1120.

Huat, B.K., Sew, G.S. and Ali, F.H., 2004. Organic and peat soils engineering. Serdang, University Putra Malaysia, Press, ISBN Number: 983-2871-08-5: pp 146.

Hwang, J., A. Humphrey, A. Bobet, M. C. Santagata., 2005. Stabilization and improvement of organic soils. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana. doi: 10.5703/1288284314216, Publication FHWA/IN/JTRP-2004/38: pp 270.

Isaia, G.C., Gastaldini, A.L.G. and Moraes, R., 2003. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement & Concrete Composites. **25** (1): 69-76.

Janz, M. and Johansson, S.E., 2002. The function of different binding agents in deep stabilization. Swedish Deep Stabilization Research Center, Linkoping: SGI. **9**: pp 48.

Jarrett, P.M., 1995. Site investigation for organic soils and peat. JKR Document 20709- 0341-95. Public Works Department Malaysia. Malaysia. Geoguide, **6**: 4-16.

Lee, S.C. and Mariatti, M., 2008. The effect of bagasse fibers obtained (from rind and pith component) on the properties of unsaturated polyester composites. Materials Letters, **62** (16): 2253-2256.

Mesri, G., Kwan, L.D.O. and Feng, W.T., 1994. Settlement of embankment on soft clays. Proc. of settlement 94, ASCE Geotechnical Special Publication, **40**: 8-56.

Mesri, G., Stark, T.D., Ajlouni, M.A. and Chen, C.S., 1997. Secondary compression of peat with or without surcharging. J. Geotech. Geoeviron. Engrg., **123** (5):411-421.

Noto, S., 1991. Peat engineering handbook. Civil Engineering Research Institute, Hokkaido Development Agency, Prime Minister's Office,Japan: 1-35.

Sales, A. and Lima, S.A., 2010. Use of Brazilian sugarcane bagasse ash in concrete as sand replacement. Waste Management, **30** (6): 1114-1122.

Sobhan, K., Reddy , D.V. and Ramirez, J.C., 2012. Cement stabilization of organic subgrades for pavement preservation. In: LACCEI (Editor), Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning Panama City, Panama: 1-10.

WBCSD, 2009. Cement technology roadmap 2009, World Business Council for Sustainable Development (W.B.C.S.D.), Internationa Energy Agency, I.E.A.: 31 pages.

Wong, L.S., Hashim, R. and Ali, F., 2013a. Improved strength and reduced permeability of stabilized peat: Focus on application of kaolin as a pozzolanic additive. Construction and Building Materials, **40**: 783-792.

Wong, L.S., Hashim, R. and Ali, F., 2013b. Utilization of sodium bentonite to maximize the filler and pozzolanic effects of stabilized peat. Engineering Geology, **152** (1): 56-66.

Wong, L.S., Hashim, R. and Ali, F.H., 2009. A Review on experimental investigations of peat stabilization. Australian Journal of Basic and Applied Sciences, **3** (4): 3537-3552, 2009. ISSN 1991-8178.

Wong, L.S., Roslan, H. and Ali, F.H., 2008. Engineering behaviour of stabilized peat soil. European Journal of Scientific Research, **21** (4): 581-591.

Symbols and abbreviations

e	Void ratio
σ'_c	Preconsolidation pressure
σ'_v	Vertical effective pressure
C_c	Compression index
C_α	Secondary compression index