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Effectiveness of Sugarcane Bagasse Ash (SCBA) as Partial Cement Replacement in Peat Stabilization

by

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Abstract

Due to high organic content, presence of humic acid and less solid particles in peat soil, cement alone is inadequate as a chemical admixture for this ground stabilization except a large quantity of cement is mixed. Sugarcane production is world number one commodities and produced a lot of bagasse. 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. These research emphases on laboratory investigation on the application of sugarcane bagasse ash (SCBA) as partial cement replacement in peat stabilization. Other than SCBA, calcium chloride ($CaCl_2$), Ordinary Portland Cement (OPC) and silica sand (K7) were used as additives to stabilize the peat that sampled from Hokkaido, Japan. To develop the optimal mix design, specimens of stabilized peat were tested in unconfined compression. Energy Dispersive X-ray (EDX) and Scanning Electron Microscope (SEM) apparatus was used to examine elemental composition and microstructure. It was found that stabilized peat comprising 20% partial replacement of OPC with SCBA has the maximum unconfined compressive strength (UCS) and discovered about 29 times greater than that of untreated peat specimen.

Keywords: Peat stabilization, Cement, Sugarcane bagasse ash, Unconfined compressive strength

1. Introduction

Peat deposits distribution is extensive and can be found in many countries throughout the world when the conditions are favorable for their accumulation and formation[1-3]. The vastness of peat land coverage and its occurrence close to or within population centers and existing cropped areas

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means some form of infrastructure development has to be carried out in these areas. To stimulate agriculture development for instance, basic civil engineering structures such as roads are required [4]. 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 [5]. These materials are very highly compressible together with very low shear strength [6].

The use of cement is not given much attention in the stabilization of organic soils because evasion is often become the first choice rather than build up any infrastructure on these problematic ground. However, over the past few years, there are researchers who began to observe the ability of the cement in the stabilization of organic soil[6-12]. It is well recognized that organic soils can retard or prevent the proper hydration of binders such as cement in binder-soil mixtures [9]. Due to high organic content and less solid particles in peat soil, cement alone is insufficient as a chemical admixture for peat stabilization. That means unless a large quantity of cement is mixed with the soil to neutralize the acids, the process of the soil stabilization remains retarded. However, adding a large quantity of cement into the peat is definitely an unfriendly and uneconomical solution to deep peat ground improvement considering the fact that the peat ground is covers a wide area, and the rising cost of cement and its transportation to the site [13]. Cement is responsible for about 5%–8% of global 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 [14].

A pozzolana is a material occurring either naturally or artificially, and which contains silica, iron and aluminum ions that can generate a pozzolanic reaction [15]. Small amount of pozzolans can be added to cement stabilized peat to enhance the secondary pozzolanic reaction in the stabilized soil [13] . One of pozzolan materials sources are getting from agricultural waste ash such as rice husk ash, straw ash and sugarcane bagasse ash. Production of large quantity of agricultural wastes all over the world faces serious problems of handling and disposal. The disposal of agricultural wastes creates a potential negative impact on the environment causing air pollution, water pollution finally affecting the local ecosystems. Hence safe disposal of agricultural wastes becomes challenging task for engineers [16].

Sugarcane production is world number one commodities with amount approximately 1.8 billion tonnes in 2012. 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 [17]. 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. However, ash can be used in place of cement or sand in civil construction [18]. Sugar cane bagasse ash (SCBA) has also been studied as a promising pozzolanic material. 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.

Therefore, it could be something very beneficial to develop alternate binders that are environment friendly and contribute towards sustainable management. Hence, the utilization of SCBA in the stabilization of peat soil can be a compelling idea and seems to be promising alternative when considering issues of energy consumption and pollution. The objective of this research works is to evaluate and clarify the effectiveness factors of SCBA as partial cement replacement in peat stabilization. It is expected that the obtained optimum mix design can be applied to stabilized shallow peat layer in order to support low to medium-volume road embankment.

2. Materials and experimental program

The materials that had been used are peat soil, Ordinary Portland Cement (OPC), silica sand so called K7, calcium chloride ($CaCl_2$) and Sugarcane Bagasse Ash (SCBA). Peat samples were obtained from Sapporo in the Hokkaido region, Japan. For the purpose of laboratory experimental samples, peat was excavated approximately to a depth of 1 m below the ground surface. The SCBA samples were brought from Shinko Sugar Industry Co., Ltd, Kagoshima prefecture in Kyushu, Japan.

Other than OPC as main binder and $CaCl_2$ as cement accelerator, well graded silica sand (K7) 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 was shown in **Table 1**.

In order to understand the chemical reaction mechanism of mixture strengthening, an Energy Dispersive X-ray (EDX) had been conducted on untreated and treated peat and expected it will provide chemical evidence on the existence of calcium which is the major element of cementation products in the stabilized peat. In addition to such chemical characterization, the scanning electron micrographs are conducted to give micro visual evidence on cementation and void refinement of the stabilized soil.

The mix designs of stabilized peat for laboratory testing are shown in **Table 2**. 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 producing each admixture, a mixer was used to intimately mix the peat with other materials for 10 minutes. Preparation of each test specimen of stabilized peat for unconfined compression test will be done by filling and tamping the stabilized soil admixture in five equal layers. Each cylinder mould has a size of 60 mm internal diameter and 300 mm height. The cylinder moulds then immersed in water for curing at specified duration under 20kPa initial pressure by using air pressure to simulate the surcharge pressure on the stabilized soil at site. After curing, the cylinder tube is removed and the test specimen is trimmed to the required size for testing. To evaluate the degree of improvement, the established parameters of the stabilized soil must be compared to those of untreated peat.

Table 1 Adopted standards for test method.

Testing Names	Standards
Atterberg Limit	JGS 0141-2009
Moisture Content	ASTM- D 2974
Particle Size Distribution	ASTM- D 422
Specific Gravity	ASTM- D 854
Organic (ash) Content	ASTM- D 2974
Fiber Content	ASTM- D 1997
Acidity (pH Test)	ASTM- D 2976
Unconfined Compression Strength	ASTM- D 2166

3. Results and discussions

3.1 Materials Properties

Table 3 displays the range values of basic properties of the peat while **Table 4** demonstrates the percentages of oxide compounds of the materials and peat. It can be seen that the peat has fiber

Table 2 Laboratory mix design.

Type of test	Description of test purpose	Curing duration (days)	OPC dosage (kgm^{-3})	Silica sand (K7) dosage (kgm^{-3})	Initial pressure (kPa)	Binder composition (abbreviation)
UCS*, pH, w**	To investigate the effect of binder composition on the tested specimens	7	300	500	20	100% OPC (C100) 95%OPC:5%SCBA (C95B5) 90%OPC:10%SCB (C90B10) 85%OPC:15%SCB (C85B15) 80%OPC:20%SCB (C80B20) 75%OPC:25%SCB (C75B25) 70%OPC:30%SCB (C70B30)

* *Unconfined Compressive Strength*

** *Water contents*

Table 3 Peat soil basic properties.

Peat soil properties	Value
Natural water content, %	580
Ash content, %	16.79
Organic content , %	83.21
Bulk unit weight (kN/m^3)	10.57
Specific gravity, G_s	1.67
Fiber content, %	43
Acidity ,pH	5.46
Liquid Limit, %	375
Compression Index, C_c	4.89
Undrained shear strength, *kPa*	6.8

Table 4 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

content between 33% and 67%, ash content exceed 15% and pH value between 4.5 and 5.5. Therefore, this peat can be classified as hemic peat with high ash content and moderate acidic [19].

With the high water content, high liquid limit and low shear strength, the studied peat demonstrated the high compressibility and instability characteristics. It is obvious that the peat has also a very low content of pozzolanic minerals with 5.48% SiO_2, 1.5% Al_2O_3 and 1.46% Fe_2O_3. In this study, OPC is predominantly characterized by 65.4% CaO, 10.26% SiO_2, 6.6% Al_2O_3 and 5.57 Fe_2O_3. Based on a review, OPC is primarily characterized by quicklime (CaO), silica (SiO_2), alumina (Al_2O_3) and ferric oxide (Fe_2O_3) [20]. With a content of 93.52% SiO_2, it can be affirmed that quartz is the major mineral in the 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 74.5% 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 C 618 Standard.

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 0.3mm in range while the size of SCBA particles consists more 80% finer than 0.045mm. According to ASTM C 618 Standard, volume fraction of more than 66% of particles smaller than 45 µm is required for a pozzolanic material.

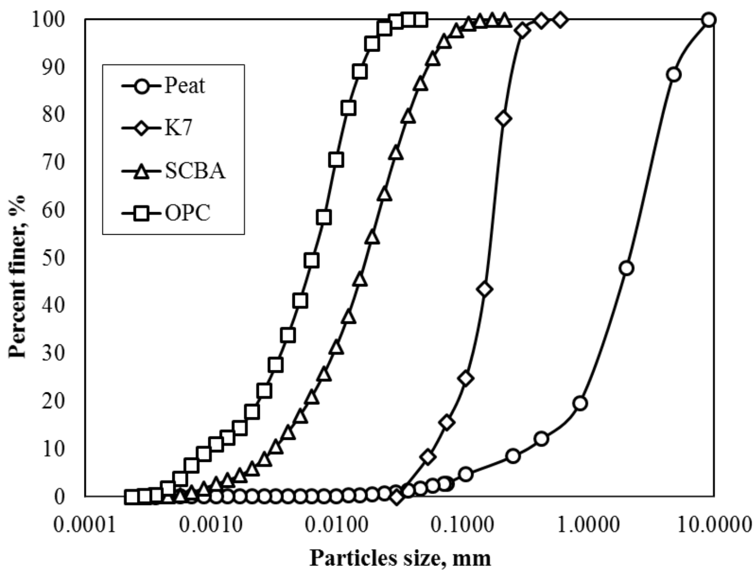

Fig. 1 Particle size distribution of peat and materials.

3.2 Effect of partial replacement of OPC with SCBA

Figure 2 shows the experimental results of the effect of SCBA on the unconfined compressive strength of the stabilized peat. An optimal unconfined compressive strength 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 2**.

It can be observed that the test specimen with 20% partial replacement of OPC with SCBA has the highest unconfined compressive strength of 387kPa and was discovered to be 29 times greater than UCS of untreated peat specimen (q_{uo}). ASTM D4609 states that an increase in unconfined compressive strength of 345kPa (adopted as minimum UCS target in this study) or more must be achieved for a treatment to be considered effective.

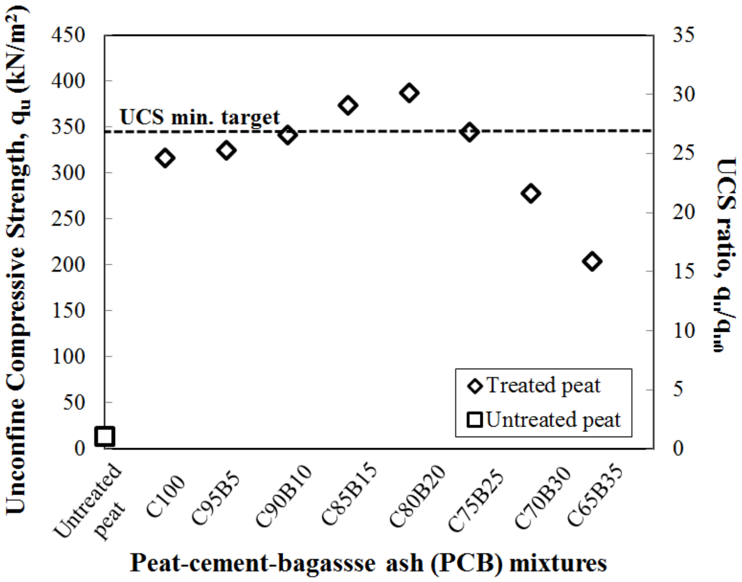

Fig. 2 Effect of OPC-SCBA on the unconfined compressive strength of the untreated and treated peat.

Figure 2 also reveal that C100 mix composition is lower than calculated optimum mix composition (C80B20). The main reasons of this condition are because peat soil consists of high organic content and less solid particles as showing in **Table 4**. Organic soils can retard or prevent the proper hydration of binders such as cement in binder-soil mixtures and become insufficient to provide the desirable function for peat stabilization. Compared with clay and silt, peat has a considerably lower content of clay particles that can enter into secondary pozzolanic reactions [9, 21]. 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 [10].

$$Cement + H_2O = 3CaO.2SiO_2.3H_2O + Ca(OH)_2 ------(1)$$
$$Ca(OH)_2 + Pozzolan + H_2O = 3CaO.2SiO_2.3H_2O -----(2)$$

The general chemical reactions between cement and pozzolan with water are denoted in Equations 1 and 2. Calcium silicate hydrate or also known as tobermorite gels ($3CaO.2SiO_2.3H_2O$) are formed when cement reacts with water in peat. This gel 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 calcium hydroxide ($Ca\ (OH)_2$) and the peat is inhibited and this renders a low strength gain in the soil-cement mixture.

The fact that the test specimen with 20% partial replacement of the cement with SCBA has the highest unconfined compressive strength may be explained by a condition whereby it has achieved an optimal effect of hydration reaction. With 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 as shown in Equation 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 secondary tobermorite gels densify the stabilized peat, thereby further enhancing its strength[13].

Generally, 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 [20]. 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 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 [22].

Figure 3 depicts the results of Scanning Electron Microscope (SEM) on untreated and some treated 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 consists of 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[23].

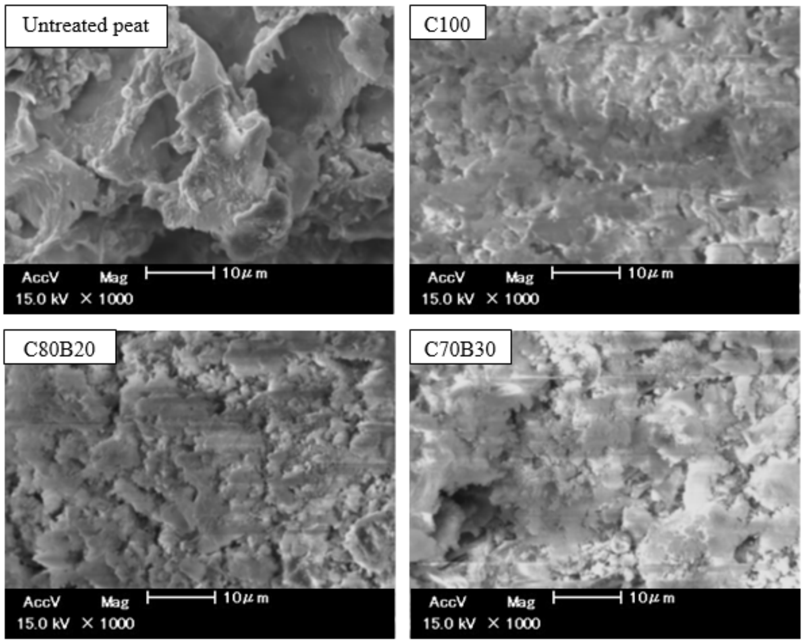

Fig. 3 Scanning Electron Microscope (SEM) on untreated and treated peat.

Minor void spaces can be detected in the photomicrographs of stabilized peats mixtures (C100, C80B20 and C70B30). Compared to C100 and C70B30 mixtures, a C80B20 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 oxide compound percentages of unstabilize and stabilized peat from EDX results are shown in **Table 5**. From this table, it is clearly depicts that lower carbon (CO_2) and higher calcium (CaO) oxide fractions shows the better results of strength. The essential pozzolanic oxide compounds (SiO_2, Al_2O_3 and Fe_2O_3) display the high values for treated peat because of SCBA and K7 presence. However this rate slightly drop at optimum mix binder (C80B20) because there is more pozzolan minerals was involved in the secondary pozzolan reaction that boosted by more calcium hydroxide [Ca $(OH)_2$]. At mix binder C70B30, carbon (CO_2) and main pozzolanic minerals (SiO_2, Al_2O_3 and Fe_2O_3) illustrates the increment value while the calcium (CaO) oxide was 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 calcium hydroxide [Ca $(OH)_2$] that could react with silica (SiO_2) and alumina (Al_2O_3) of SCBA to yield secondary pozzolanic products during the pozzolanic reaction.

Table 5 Energy Dispersive X-ray (EDX) test results of untreated and treated peat.

Oxide Compound	Untreated Peat, %	Stabilized Peat, %		
		C100	C80B20	C70B30
CO_2	78.86 ± 7.92	8.76 ± 2.90	5.17 ± 1.24	25.88 ± 2.33
NA_2O	0.32 ± 0.01	0.15 ± 0.02	0.26 ± 0.08	0.32 ± 0.08
MgO	0.63 ± 0.25	0.64 ± 0.10	0.98 ± 0.33	0.96 ± 0.40
Al_2O_3	2.95 ± 1.45	5.64 ± 1.19	4.92 ± 0.09	6.63 ± 0.14
SiO_2	9.55 ± 4.07	24.21 ± 6.68	17.21 ± 1.22	23.63 ± 0.8
P_2O_5	2.33 ± 0.39	1.38 ± 0.06	2.83 ± 0.00	1.26 ± 0.35
SO_3	0.22 ± 0.00	1.36 ± 0.06	2.97 ± 1.69	2.42 ± 0.02
K_2O	0.92 ± 0.28	2.26 ± 0.34	2.77 ± 0.64	4.48 ± 0.27
CaO	0.43 ± 0.23	51.09 ± 3.94	56.72 ± 4.7	30.14 ± 0.88
TiO_2	0.89 ± 0.23	1.35 ± 0.05	2.29 ± 0.62	0.76 ± 0.02
Fe_2O_3	3.04 ± 1.58	3.19 ± 1.4	3.92 ± 2.06	3.55 ± 0.10
$Al_2O_3+SiO_2+Fe_2O_3$	15.54 ± 7.1	33.04 ± 9.27	26.05 ± 3.37	33.81 ± 1.04

4. Conclusions

Utilization of sugarcane bagasse ash (SCBA) as partial cement replacement in peat stabilization has been examined. It can be summarized from the experimental results that SCBA has made a significant influence on the physical, mechanical and chemical properties of the stabilized peat. Based on the outcome of the laboratory analysis, the following concluding comments are made.

i. Untreated peat in this study can be classified as hemic peat with high ash content and moderate acidic. With the high water content, high liquid limit and low shear strength, this soil demonstrated the high compressibility and instability characteristics.

ii. It was found that the summation of the vital pozzolanic oxide compounds (SiO_2, Al_2O_3 and Fe_2O_3) for SCBA that had been used is 74.5% of the total oxide compounds which is indicate the suitability of this materials as a pozzolan since the amount of such oxide compounds exceeds 70% as recommended by ASTM C 618 Standard.

iii. It was observed that the test specimen with 20% partial replacement of OPC with SCBA has the highest unconfined compressive strength of 387kPa and was discovered to be 29 times greater than that of untreated peat specimen.

iv. 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.

v. EDX results prove that the lower carbon (CO_2) and higher calcium (CaO) oxide fractions will gave the better results of strength.

Overall, it is suggested that the obtained optimum mix design can be applied to stabilize the shallow peat layer in order to support road embankment for low to medium-volume road.

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