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Research Paper

Effect of bamboo leaf ash addition in cemented bamboo chips-sand soil mixture

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ABSTRACT

Utilization of natural materials as a solution to the problems in the geotechnical engineering field has been widely developed. It is necessary to reduce the utilization of cement due to its production contributes to high CO_2 emission to the environment. Selection of the natural material considers the potential of availability and workability. Bamboo, as one of the natural resources, is easy to obtain due to its ability to grow in varying conditions. In the form of bamboo chips and bamboo leaf ash, there are high water absorbability and pozzolanic content, respectively. Effect of bamboo materials addition in the mixture to the mechanical properties was investigated. Many variations in the mixture were performed to determine the effect of cement replacement by bamboo material. Aspect of geo-environment becomes the main goal of this study through the utilization of natural materials in soil improvement. Furthermore, the environmental impact by material addition can be investigated by life cycle assessment.

1. Introduction

Mixing method by stabilizer material into soil is widely applied method to improve the properties. Cement is the stabilizer agent widely used and applicable to the various types of soil. It is because the performance of cement does not depend on the type of minerals in the soil, but due to the reaction between cement and water. This reaction provides bonding, hardening and strengthening in soil stabilization (Ates, 2016).

In some cases, the utilization of cement in soil improvement is the final selection since others are more costly. However, soil improvement by cement is still considered as a quite expensive alternative material, especially in some developed countries. Moreover, in the subgrade design, poorly graded sandy soil is a soil type that is more stable compared to the expansive clay or organic soil. Thus, generally, improvement poorly graded sandy soil is not required for saving the cost. However, if poorly graded sandy soil is in loose, confined, saturated, and potentially receiving large earthquakes, it leads to receive liquefaction phenomenon. In these conditions, cement can be utilized to stabilize poorly graded sand.

In the environmental aspect, cement production is an important concern. Based on Synthesis Report of Climate Change 2014 by IPCC, cement production contributes 34.8GtCO_2/yr annual CO_2 emission together with fossil fuel combustion and flaring. Since 1970, these activities have tripled. Therefore, there are some studies proposing substitution materials to reduce cement utilization, including the addition of high pozzolanic materials or reinforcement in the cemented sandy soil such as fly ash, nanosilica, zeolite, glass fiber (Choobbasti et al., 2015; Mola-Abasi and Shooshpasha, 2016; Ates, 2016).

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Nowadays, the investigations also began to focus on the sustainability. Thus, natural materials become the main concern in this effort.

Bamboo is a kind of natural resource that has ability to grow in varying conditions, especially in tropical and sub-tropical countries. It is an extremely diverse plant, which easily adapts to different climatic and soil conditions (Lobovikov et al., 2007). The utilization of bamboo has been widely known in several applications. In this study, parts of bamboo used are culm and leaf. In the form of bamboo chips produced by chipped bamboo culm and combined with cement is expected to improve poorly graded sandy soil. Huang et al. (2011) and Saki et al. (2013) investigated bamboo chips utilization to improve the soft ground with low bearing capacity and to increase erosion resistance, respectively. Moreover, Sato et al. (2014) studied bamboo chips and flakes utilization in high water content of excavated mud. However, the combination between pozzolanic content of cement and high water absorbability of bamboo chips in the poorly graded sand under saturated condition has not been investigated yet.

Bamboo leaf ash (BLAsh) is also used in this study. It is based on the background about most part of bamboo used is the bamboo culm, whereas the utilization of bamboo leaf is still not maintained well. In Japan and Indonesia, bamboo leaf is unused, only used as a natural fertilizer, or burned in open area. It informs that this material is a waste with low value. It is also the problem of some countries that have high potential of bamboo resources and require recycling as one of the solutions to agricultural wastes, i.e. Brazil, Nigeria, and India. It is shown by the presence of several researches which developed the utilization of bamboo leaf in these countries. In the form of BLAsh, some studies investigated its utilization as alternative material with high availability, low processing cost and ease of handling with little or no equipment and skill requirements to replace cement (Utodio et al., 2015). Dwivedi et al. (2006), Singh et al. (2007), Frias et al. (2012), Villar-Cocina et al. (2011), and Asha et al. (2014) investigated the characterization and determination of pozzolanic content of BLAsh. They concluded that BLAsh has ability to replace cement material due to the content in some applications. BLAsh has been proved able to be partial replacement of cement in cement paste and mortar (Umoh and Odesola, 2015), in concrete (Asha et al., 2014 and Umoh and Femi, 2013), in lateritic blocks (Utodio et al., 2015) in improvement of shale for road structure (Iorliam et al., 2013), and in stabilization of lateritic soil in highway construction (Amu and Babajide, 2011; Amu and Adetuberu, 2010; Dada and Faluyi, 2015).

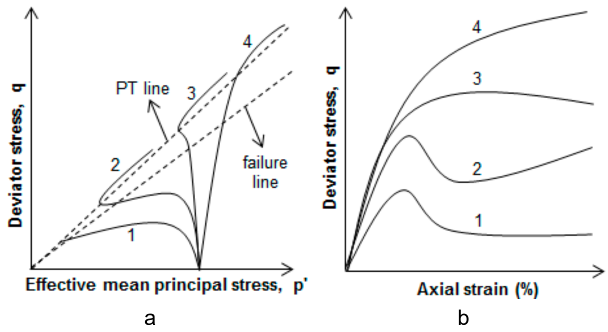


Fig. 1. Flow deformation behavior of sand in monotonic test (a) effective stress path and (b) relationship between deviator stress and axial strain (modified after Hyodo et al. (1994) and Mohamad and Dobry (1986)).

Regarding liquefaction as a typical phenomenon of loose and poorly graded sand in saturated condition, triaxial compression test under static or monotonic loading and confining effective stress can be conducted to perform increasing pore water pressure that develops large shear phenomenon of soil mass. This phenomenon is called as static liquefaction. When the strain level is large enough, soil samples under sharing tend to be in a state of continuous deformation under constant shear and normal stress. Relative density, confining pressure and static shear stress are factors affecting this behavior. Also, static liquefaction might be studied using triaxial apparatus to obtain a better understanding of the occurrence of flow type of failure Salamatpoor and Salamatpoor (2014).

In undrained condition, sand has three main behaviors in monotonic triaxial test, i.e. dilative, limited/partially-contractive, and fully contractive (Hyodo et al., 1994; Jafarian et al., 2013; Igwe et al., 2004; Ishihara et al., 1975; Mohamad and Dobry, 1986; Ibsen, 1998; Vaid and Chern, 1983). Based on **Figs. 1(a)** and **1(b)**, contractive behavior is shown by Curve 1. In this behavior, increasing deviator stress is followed by its decreasing to constant value called by steady state or residual state (Hyodo et al., 1994). Limited/partially-contractive is presented by Curve 2. This behavior is shown by “elbow” shape formed by reaching the maximum deviator stress then together with the strain softening emerged at a certain stage of shear to a minimum deviator stress before turned and ascended along the failure line (Hyodo et al., 1994; Jafarian et al., 2013; Igwe et al., 2004; Ishihara et al., 1975; Mohamad and Dobry, 1986; Ibsen, 1998). The elbow was observed in this study as comparison of dilation tendency. Based on the **Fig. 1(a)**, elbow is shown by Curve 3, but in **Fig. 1(b)**, relationship between deviator stress and axial strain of Curve 3 shows increasing deviator stress during loading. It shows flow tendency, but hardening is occurred toward dilation. Dilative behavior is shown by

Curve 4. Increasing deviator stress is always occurred during loading.

One of the properties that affect the dilative behavior of sand is the coefficient of permeability. Rahmani et al. (2012) conducted some simulations using numerical analysis on liquefaction phenomenon. They concluded about the importance of soil permeability coefficient to predict the pore pressure and displacement. Moreover, Ramirez (2010) showed the sensitivity of loose and poorly graded sand behavior due to permeability value. It was found that the higher soil permeability, the weaker soil dilation. Based on these considerations, investigation to the coefficient of permeability was also required to ensure the effect of bamboo chips to dilative behavior of cemented sandy soil.

In this study, utilization of BLAsh as cement replacement in soil improvement is the proposed method to utilize environmental waste and reduce cement in geotechnical point of view. As a new material, evaluation of manufacturing process of BLAsh regarding its impact to environment is required. It was conducted to determine its sustainability. Thus, effectiveness of BLAsh utilization in comprehensive aspect is acceptable. Analysis of environmental impact conducted is Life Cycle Assessment (LCA). Based on ISO 14040:2006, definition of LCA is compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. Product has definition as material that leaves the unit process which in this study refers to BLAsh and cement. There are four phases in an LCA study, i.e. the goal and scope definition, the inventory analysis, the impact assessment, and the interpretation. Garrigues et al. (2012) analyzed the LCA of soil quality. In this study, analysis conducted focuses on comparison of impact to environment due to manufacturing process between cement and BLAsh by reason of comparison of the two materials have same functions in the mixture. In addition, analysis of CO_2 emission becomes important to determine whether the BLAsh as a new proposed material in geotechnical field is able to prove as environmentally friendly materials in reducing CO_2 emission in its manufacturing process compared to cement. This study is called as Life Cycle CO_2 ($LCCO_2$). Noda et al. (2001), Nakamura and Kondo (2002) were also utilizing $LCCO_2$ concept to analyze environmental impact in geotechnical applications.

The objective of this research is to investigate the effects of bamboo materials, i.e. bamboo chips and BLAsh, to poorly graded sandy soil. The materials have different function in mixture. By the high absorbability, bamboo chips are able to absorb water in the void of saturated sandy soil and increase strength of the mixture, whereas BLAsh which has a high pozzolanic content is expected to replace cement. Variations bamboo chips and BLAsh were conducted to determine the optimum mixture in soil improvement. To obtain comprehensive result, analysis, comparison, and investigation to the mechanical, chemical, and environmental impact are performed.

2. Material and experimental Program

2.1 Soil properties

Poorly graded sandy soil used in this study was based on the properties of liquefied soil occurred in field. It aims to generalize and approach actual conditions, so this proposed method is applicable in field. Based on this consideration, selection of soil type in this paper is based on this investigation result by Koseki et al. (2007). The summary contains report of liquefaction phenomenon occurred in several sites in Yogyakarta City in Java Island, Indonesia after Mid Java Earthquake on May 27, 2006. There are compatibility properties of Toyoura sand with liquefied soil. **Figure 2** shows that the grain size distribution curve of Toyoura sand is located among the other curves. The index properties of Toyoura sand are G_s = 2.64, D_{50} = 0.17 mm, U_c = 1.75, e_{max} = 0.953, e_{min} = 1.352. In all mixture variations, Toyura sand was kept at a constant relative density (D_r) of 35%.

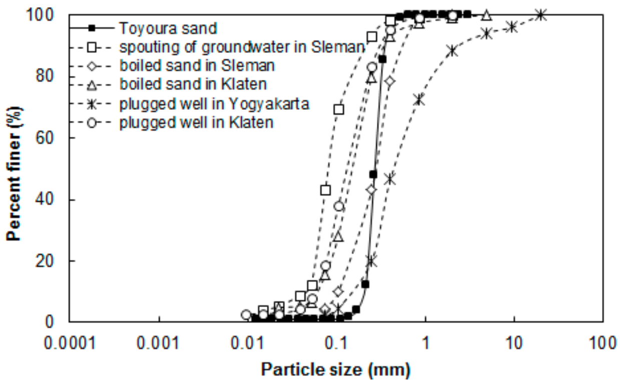
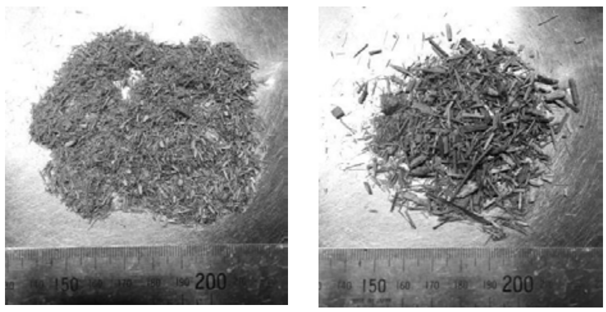


Fig.2. Particle size distribution curve of the liquefied soil in several sites in Indonesia (modified after Koseki et al. 2007).



a b

Fig. 3. Bamboo chips (a) 6 mm and (b) 10 mm.

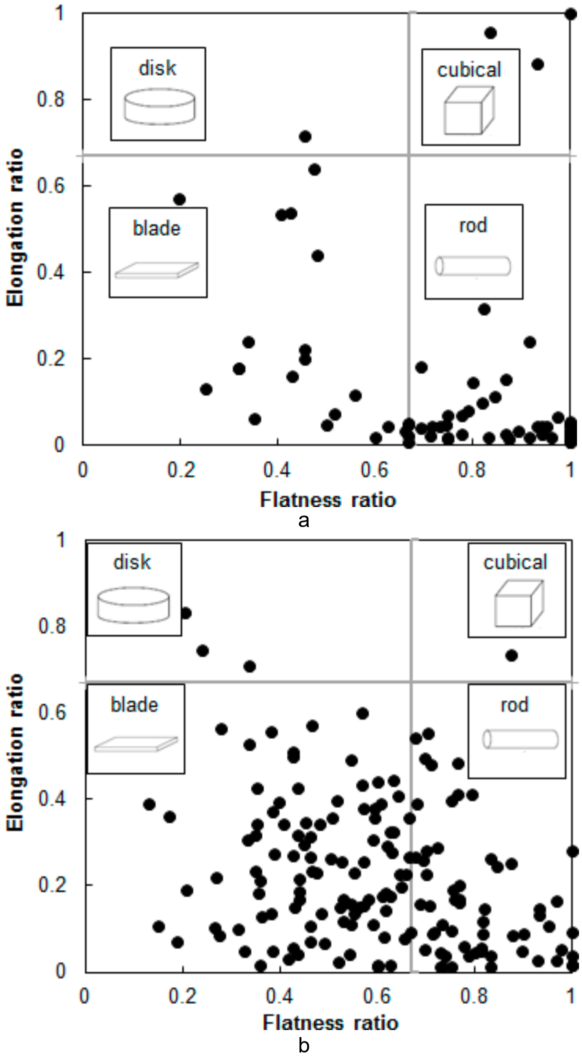


Fig. 4. Elongation and flatness ratio of (a) 6 mm and (b) 10 mm bamboo chips.

2.2 Bamboo chips

Bamboo chips are made from bamboo culm obtained from Nouken Sangyou Co. Ltd and produced using cutting machine. In this study, there are two types of bamboo chips based on the longest size of chips, i.e. 6 and 10 mm shown in **Fig. 3**. The physical characterization of bamboo chips is performed by elongation and flatness ratio. Elongation ratio is a ratio between intermediate and shortest length of bamboo chips particle, whereas flatness ratio is the ratio between shortest and longest length. Particle length measurement was conducted using digital caliper.

2.2.1. *Elongation and Flatness Ratio*

Based on the elongation and flatness ratio parameters, particles are divided to be four shapes, i.e. disk, cubical, blade, and rod. The limit of these shapes is 2/3 value of each parameter (Chen et al., 2005). In the densification process, each shape of particle has typical characteristic in mixture. But, in compaction process, cubical is the best shape in the workability reason. Both types of bamboo chips have same dominant shape, i.e. blade and rod. It can be seen in **Fig. 4** that depicts the elongation and flatness ratio of bamboo chips. However, 6 mm bamboo chips have cubical shape and its size is smaller, so the compaction process of specimen with 6 mm bamboo chips content is easier.

2.2.2. *Water absorbability*

As an important parameter, water absorbability of bamboo chips was investigated. The water absorbability of bamboo chips provides potential to decrease the excess pore water pressure of soil mixture in undrained condition during loading. **Figure 5** shows the water absorbability tendency of bamboo chips. Based on the test result, absorbed water of 6 mm bamboo chips is higher than 10 mm bamboo chips. In the larger size, water requires longer time to saturate the bamboo chips. This result proves that shape factor has significant effect to the water absorbability.

Water absorbability test was conducted to obtain absorbed water in a constant volume of cylinder sample. The dimensions of sample are 6 cm diameter and 1.5 cm height. The initial water content was kept less than 5%. Bulk density of the bamboo chips is about 0.2 gram/cm^3. A simple procedure of the absorbability test that can be seen in **Fig. 6** was developed by connecting the bamboo

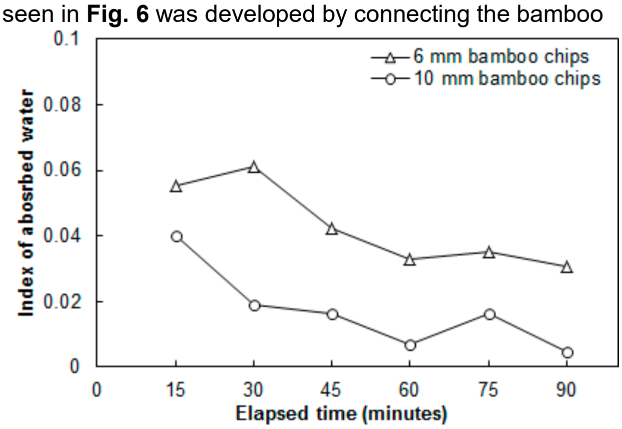


Fig. 5. Absorbed water index of bamboo chips in 90 minutes.

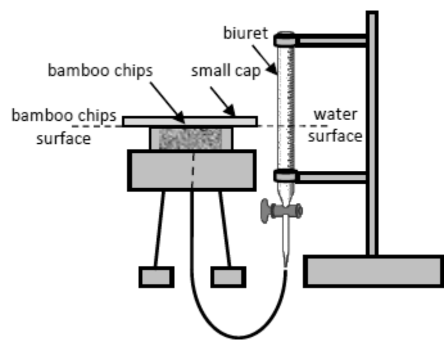
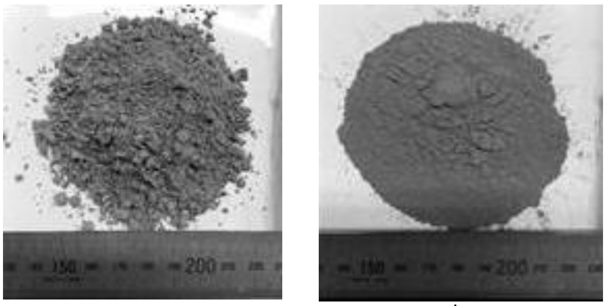


Fig. 6. Concept of absorbability test apparatus.



a b

Fig. 7. (a) BLAsh and (b) Portland cement.

Table 1. Chemical Composition of BLAsh and Portland Cement by EDX Test

Elemental Oxide	Percentage by mass (%)	
	BLAsh	Portland Cement
CaO	6.00	65.03
SiO_2	78.29	19.72
Al_2O_3	1.21	2.06
Fe_2O_3	0.72	0.72
MgO	1.21	0.85
K_2O	5.03	0.63
Na_2O	-	-
SO_3	1.87	2.75
TiO_2	-	0.46
P_2O_5	-	4.90

chips cylinder with biuret contains distilled water. Water flowed to the bottom of bamboo chips. At the same time, upper part of bamboo chips was detained in order to keep the volume by using small cap to avoid the over pressure. Water surface in biuret was maintained as high as bamboo chips surface during the test. The decreasing water in biuret is the absorbed water volume. Tests were conducted for 90 minutes. Calculation of absorbed water index was conducted to provide understanding and comparison between both of the bamboo chips types. Absorbed water index is ratio between the decreasing water in biuret and volume of bamboo chips.

2.3 Pozzolanic materials

In this study, there are two types of pozzolanic materials used, i.e. cement and BLAsh, shown in **Fig. 7**. In the first stage, cement addition aims to investigate the effect of bamboo chips in cemented sandy soil, whereas in the second stage, combination between cement and BLAsh is added to propose BLAsh in reducing cement content.

The cement used in the study was ordinary Portland cement. It was obtained from cement company in Japan. In the AASHTO soil classification, Toyoura sand used in this study is classified in A-3 namely non-plastic sand soil. Portland Cement Association (1956) provided guideline to determine the optimum cement content for stabilization purposes. Percentage of cement suggested for A-3 soil is 7-11%. This guideline is used for the rough range in practice and research activities. In this study, to reduce cement utilization in soil improvement and to obtain the information regarding tendency of small amount of cement utilization, variations of cement percentage were chosen less than suggested amount in guideline.

Bamboo leaf waste was obtained from Nouken Sangyou Co. Ltd. BLAsh was produced in Geotechnical Laboratory, Kyushu University. Dry bamboo leaf was burnt in an open air, stopped after it becomes black in color, and then heated in furnace at 600˚C for 2 hours to produce bamboo leaf in grey in color. Once heated, it was cooled and grinded using mortar and pestle, then sieved using 75 μm mesh wire. The BLAsh is made in the constant temperature (about 20ºC). The most important of the making process of the BLAsh is the storage after finish the process. It must be kept in the closed storage to avoid the agglomeration by air or water. BLAsh is produced about 10% to dry mass of dried bamboo leaf. Based on Umoh and Odesola (2015), specific gravity (G_s) of BLAsh is 2.64, whereas Portland cement is 3.10.

The amount of SO_3 and the total amount of SiO_2, Al_2O_3, and Fe_2O_3 describe the chemical requirements of the pozzolans. ASTM C618–03 mentioned the minimum amount of SiO_2, Al_2O_3, and Fe_2O_3 is 50% for class C and 70% for class N and F pozzolans, whereas the maximum amount of SO_3 is 4% for class N and 5% for class F and C pozzolans. Class N is raw or calcined natural pozzolan, class F is pozzolanic fly ash from burning anthracite or bituminous coal, whereas class C is pozzolanic and cementitious fly ash from burning lignite or bituminous coal. Based on the result of Energy Dispersive X-ray (EDX) test in **Table 1**, the amount of SO_3 and the total amount of SiO_2, Al_2O_3, and Fe_2O_3 are 1.87% and 80.22%, respectively. This result shows that BLAsh is classified as class N pozzolan.

2.4 Mixture variations

The dimensions of specimen are 50 mm diameter and 100 mm height in cylinder. The mixture variations are presented in **Table 2**. Water addition of 20% was decided based on the preliminary trial considering the workability reason. The percentages of water and pozzolan referenced to dry mass of Toyoura sand, whereas percentage of BLAsh are referenced to pozzolan. Specimen was prepared by mixing soil, bamboo chips, cement, and BLAsh in dry condition into a homogeneous color mixture then pour water into the mixture. Compaction was conducted in acrylic cylinder. After curing, acrylic cylinder was removed. Generally, pozzolanic materials have the ability in hardening process by hydration over the time. Singh et al. (2000) and Shi and Day (2001) investigated the curing time effect of baggage ash as natural pozzolan blended with

Table 2. Mixture Variation in Stages Investigation

Toyoura sand (D_r, %)	Water addition (%)*	Aim	Total pozzolan (%)*	Ratio by total pozzolan			Bamboo chips (%)*	Mixture code
				BLAsh	:	Portland cement		
35	20	1**	-	-	:	-	-	T
							6 mm 1%	TB_61
							6 mm 2%	TB_62
							10 mm 1%	$TB_{10}1$
							10 mm 2%	$TB_{10}2$
			4	0	:	1	-	TC4
							6 mm 1%	$TC4B_61$
							6 mm 2%	$TC4B_62$
							10 mm 1%	$TC4B_{10}1$
							10 mm 2%	$TC4B_{10}2$
		2***	2	0	:	1	6 mm 2%	$TC_{100}BL_0$
				1	:	3		$TC_{75}BL_{25}$
				1	:	1		$TC_{50}BL_{50}$
				3	:	1		$TC_{25}BL_{75}$
				1	:	0		TC_0BL_{100}

Notes:
*The percentages are referenced by dry weight of Toyoura sand
**Aim 1 = to obtain the effectiveness of bamboo chips in cemented sandy soil
***Aim 2 = to obtain the effectiveness of BLAsh in bamboo chips-cemented sandy soil

cement and lime-pozzolanic cement mixture in varied conditions, respectively. They stated that the high increment of compressive strength and pozzolanic reaction rate are in the early stage of curing time, i.e. 7 days or less. The strength and reaction are still increasing after 7 days, but the increment is not significant approaching 28 days. It shows that the specimen age of 28 days is estimated as the optimum age by its nearly constant strength. The objective of this study compares among the mixture variations during hardening process. By this reason, 7 and 14 days are applied for curing time period. In the first stage, to determine the effectiveness of bamboo chips in cemented sandy soil, mixtures are cured for 7 and 14 days, whereas in the second stage, to obtain the optimum BLAsh content in bamboo chips-cemented sandy soil, mixtures are cured for 7 days.

2.5 Laboratory testing program

This study performed the effectiveness of the bamboo chips and BLAsh in the cemented sandy soil in the various curing time based on the type of test. To perform the flow of research and consistency of variable, this study is divided into three stages. The first stage is to determine the effect of type and content of bamboo chips in the cemented sandy soil mixture based on the permeability test and undrained static or monotonic triaxial test under dilative behavior observation. Permeability was conducted by using constant head method (ASTM 2434-68). In the second stage, using the conclusion of the first stage, an investigation to the effectiveness of BLAsh as a cement replacement was performed. Observation was conducted using static triaxial test results and calculation of CaO/SiO_2 ratio as an important indicator of improvement by pozzolanic material. Generally, the higher ratio performs the higher improvement. However, the variation of CaO and SiO_2 availability in pozzolanic material performs different tendency (Tastan et.al., 2011). The ratio was obtained based on the percentage analysis by weight of combination between cement and BLAsh. The percentage variation of each material is shown in **Table 2.** The chemical contents of each material are shown in **Table 1**. Based on this second stage, the optimum percentage of BLAsh was proposed. Furthermore, the last stage is the investigation of the environmental impact of BLAsh manufacturing process compared to cement by LCA method.

Undrained static or monotonic triaxial test conducted in the first and second stages used consolidated-undrained method with the pore water pressure measurement during loading (ASTM 4767-11). In this test, to obtain high degree of saturation, de-aired water was circulated in the specimen by using double negative pressure method. In addition, back pressure of 200 kPa was applied. B-values of more than 0.9 were observed in all. The test was performed at 50, 100, and 150 kPa of confining pressure. Strain was controlled after isotropic consolidation. The samples were executed by applying a monotonic axial load with a strain rate of 0.1%/min.

In the first stage, results of static triaxial test are performed in the stress path. Stress parameters p' and q are used for representing the effective mean principal stress, $p' = (\sigma'_1+2\sigma'_3)/3$, and the deviator stress, $q = \sigma'_1-\sigma'_3$, respectively. In the second stage, results of static triaxial test are shown in the comparison of q_{max} that was also considering the silica content in the mixture to obtain optimum mixture. The q_{max} is the peak value of deviator stress in the stress-strain curve of the triaxial test result. But, if there is no peak in the curve, deviator stress at 15% ($q_{at15\%}$) of strain is selected as the q_{max}.

3. Evaluation of bamboo chips utilization in cemented sand soil

3.1 Coefficient of permeability

In liquefaction phenomenon, pore water pressure of loose sandy soil increases in short time due to earthquake loading. This increasing pore water pressure causes zero effective shear strength. The dissipation of pore water pressure is the dominant mechanism after the seismic or earthquake loading ceases. During liquefaction, the soil permeability may increase significantly due to the reduction of contacts among particles causing large displacement. It shows that the larger pore shape, the larger path for water to flow and larger displacement. Thus, the ability of water to flow or drainage that is generally called as coefficient of permeability is the important parameter in the liquefaction phenomenon (Ramirez, 2010). Based on this consideration, to reduce the contractive soil response as main characteristic of liquefiable soil, decrease the coefficient of permeability by bamboo chips is the objective of this research.

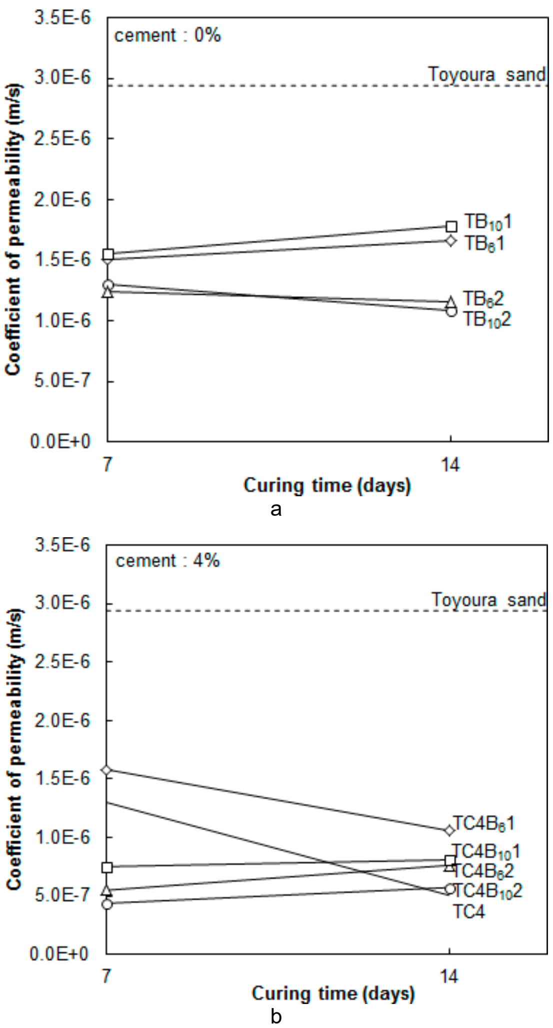


Fig. 8. Coefficient of permeability (a) without cement and (b) with 4% cement in mixture.

Besides its ability to absorb water in the void, bamboo chips are also expected to hamper water to flow in the void. This effect of bamboo chips is able to provide time for water to flow defined as decreasing coefficient of permeability. It can be seen in the result of the permeability test to the mixtures in some variations.

In the mixture without cement, bamboo chips addition provides significant effect to the coefficient of permeability. **Figure 8(a)** shows the decreasing of permeability coefficient about 47-58% and 40-63% of bamboo chips addition after 7 days and 14 days curing time compared to Toyoura sand, respectively. Based on this result, size factor of bamboo chips provides slight effect. It can be seen from adjacent lines between 6 mm and 10 mm of bamboo chips on the same percentage content in **Fig. 8(a)**. However, the quantity factor and curing time have an influence on the coefficient of permeability. This is indicated by the different slope of the curve between 1% and 2% of cement content in **Fig. 8(a)**. The higher content of bamboo chips, the lower of permeability coefficient. Based on the influence of curing time, there is also information that the addition of 1% of bamboo chips gives a negative effect over time because small amount of bamboo chips allows water to saturate in a short time. There is intersected curve in the 2% of bamboo chips content. It might be due to less homogeneous mixture resulted by lack of proper mixing during specimen preparation.

Pozzolanic content in cement presents different tendency. This information can be seen in **Fig. 8(b)**. The decreasing coefficient of permeability of 4% cement added into Toyoura sand was provided by the cementation reaction. The decreasing void in sand soil is an effect of the bonding reaction between cement and water. Moreover, bamboo chips addition provided varying tendency. After 7 days curing time, permeability coefficient of the specimen with 1% and 2% content of 10 mm bamboo chips and 2% content of 6 mm bamboo chip were lower than the cemented sand. However, after 14 days curing time, these mixtures increased. It can be approved that cementation reaction might be hampered due to the presence of the bamboo chips as additive material in large quantities. The mixture that has the same characteristic as cemented sandy soil is mixture with the addition of 1% of 6 mm bamboo chips in the cemented sandy soil. Based on this result, factor of size and content of bamboo chips presents significant effect on the coefficient of permeability. In this investigation, the 6 mm bamboo chips were concluded able to show the improvement regarding reduction of coefficient of permeability in cemented sandy soil.

3.2 Dilative behavior

Dilative behavior of sand soil can be interpreted by investigating the stress path as a result of the static or monotonic triaxial test. **Figures 9** and **10** depict result of cemented sand soil test. Elbow shape in **Fig. 9** that indicates the softening behavior is not fine. It can be approved that the cemented sand soil has dilative behavior. Based on this result, addition of the bamboo chips in the mixture has to be investigated to obtain the optimum type and content as proposed additive material in the cemented loose and poorly graded sand soil improvement.

In this study, the comparison of the properties contained in the specimen is presented only on the application of 100 kPa of confining pressure. This boundary provides focus discussion in order to provide understanding of each parameter effect. There are three parameters compared, i.e. variation of bamboo chips size and content, curing time, and cement content.

Observation is focused on the stress path behavior, especially on the elbow characteristic line that depicts the

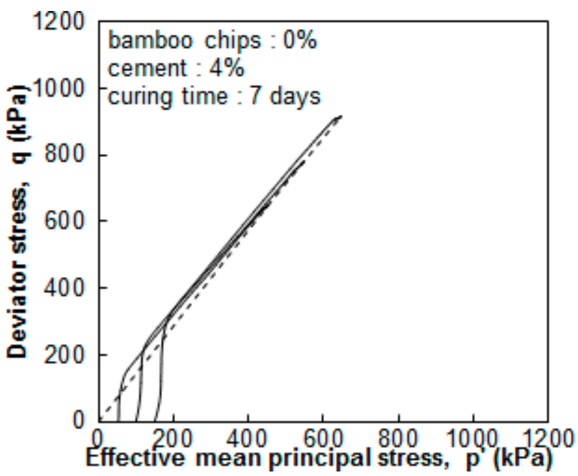


Fig. 9. Stress path of the cemented sand soil.

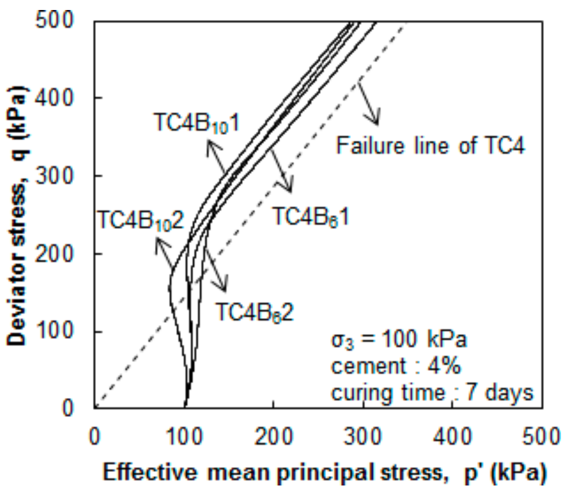


Fig. 11 Stress path in variation of bamboo chips size and content in cemented soil.

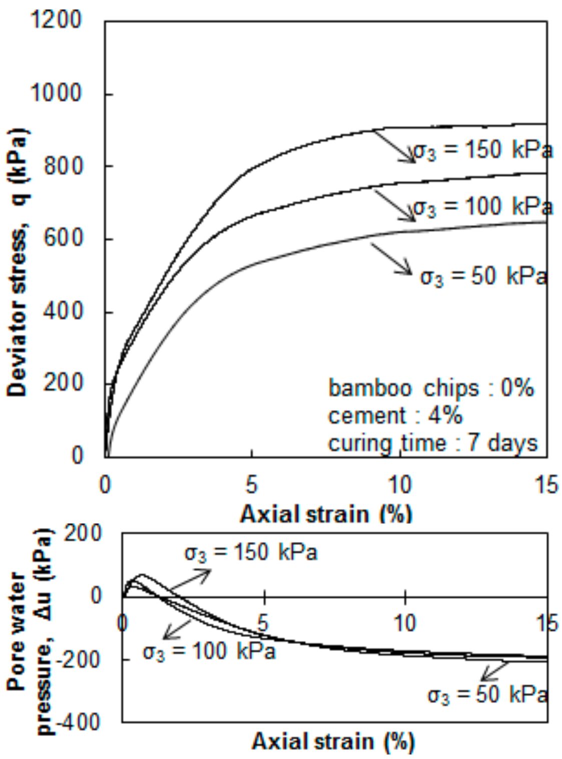


Fig. 10 Stress-strain relationship and pore water pressure of cemented sand soil.

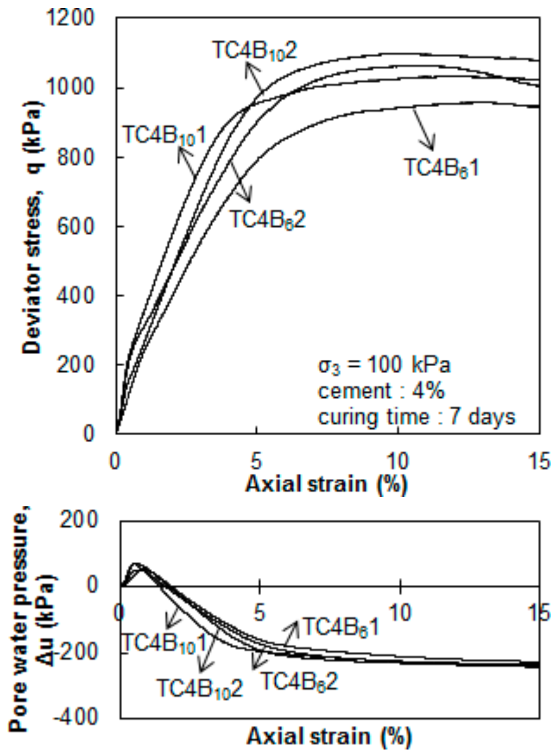


Fig. 12 Comparison of stress-strain relationship and pore water pressure in variation of size and content of bamboo powder.

dilative behavior of specimen. In the dilative behavior of cemented sand soil, factor of size and content of bamboo chips has main effect. Based on **Fig. 11**, after 7 days curing time, it can be seen that the highest stress path is reached by addition of 1% content of 10 mm bamboo chips. However, the upright curve is reached by addition of 2% content of 6 mm bamboo chips. It proves that 10 mm bamboo chips in small amount are able to improve the strength of the specimen using its form, while bamboo chips of 6 mm allow cement to react with water due to its small size. In accordance with the absorbability test, water can be easily absorbed by small bamboo chips. This can be concluded that cemented reaction is the main factor in addition of small bamboo powder.

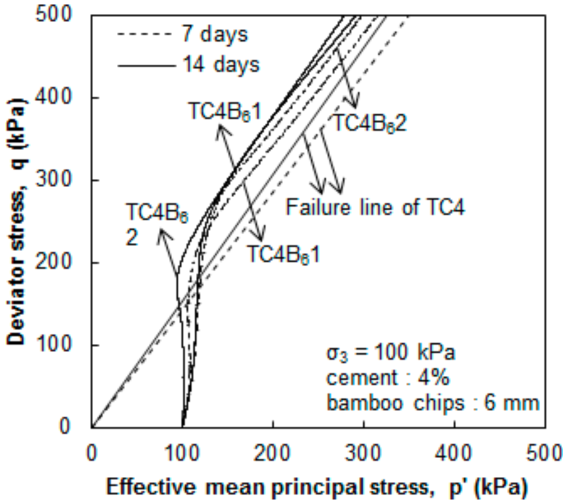


Fig. 13 Stress path in variation of curing time (6 mm bamboo chips).

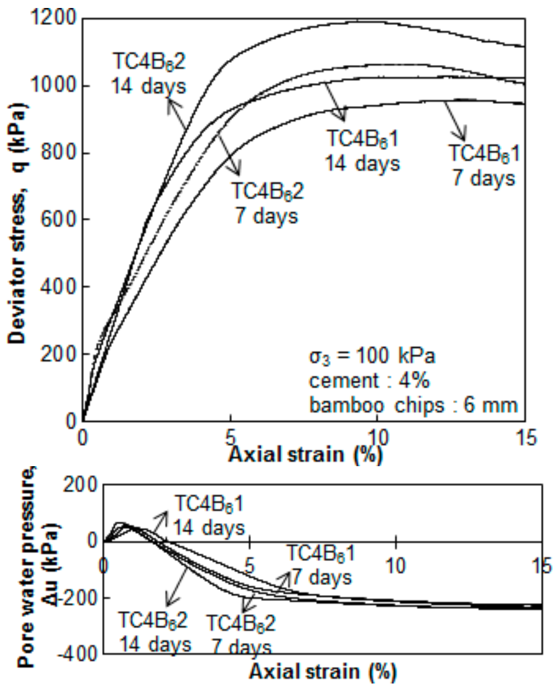


Fig. 14 Comparison of stress-strain relationship and pore water pressure in variation of size and content of bamboo powder (6 mm bamboo chips).

Variation of the curing time can be seen in **Figs. 13-16**. This information provides slight differences based on the adjacent curve. Based on observation of elbow shape and characteristic of stress path in **Figs. 13** and **15**, after 14 days curing time, improvement of specimen is shown by both types of bamboo chips. Positive tendency of the curing time is also shown in the stress-strain relationship curve in **Figs. 14** and **16**. This variation result shows that time dependency is also the main factor of this improvement of the loose and poorly sand.

Variation of cement content is shown in **Fig. 17**. It shows that cement addition provides higher result compared to the utilization of bamboo chips only. This can be concluded that bamboo chips are not suitable as a substitute of cement material. However, addition of

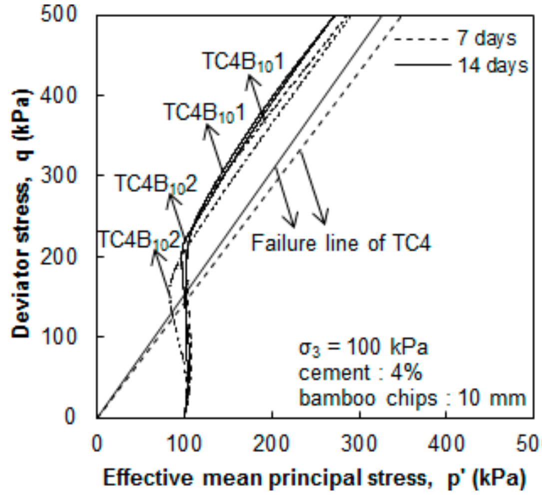


Fig. 15 Stress path in variation of curing time (10 mm bamboo chips).

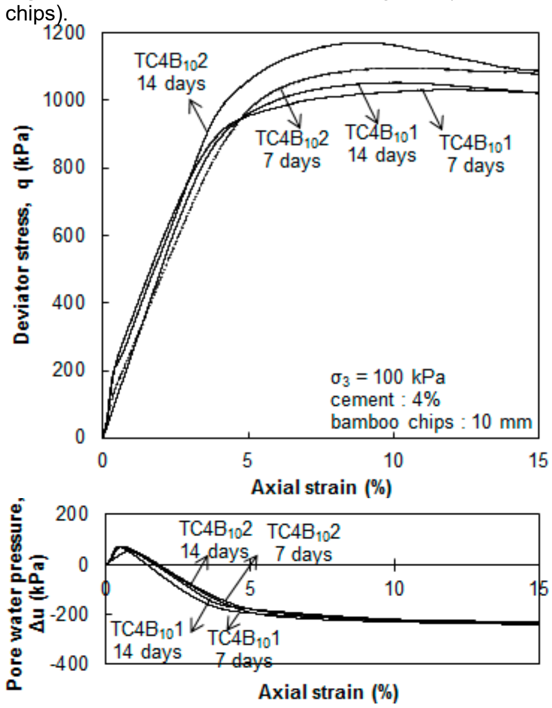


Fig. 16 Comparison of stress-strain relationship and pore water pressure in variation of size and content of bamboo powder (10 mm bamboo chips).

bamboo chips improves the strength of cemented sand. This statement is approved by the comparison of results that can be seen in **Fig. 18**. It shows that the higher content of bamboo chips, the higher strength of the cemented sand.

Based on the result of dilative behavior investigation, 6 mm bamboo chip showed optimum improvement in the cemented sandy soil. This conclusion is in the line with the previous results, i.e. physical characteristic by elongation and flatness ratio, water absorbability, and coefficient of permeability.

4. Utilization of BLAsh in cemented bamboo chips-sand mixture

This stage followed the conclusion of previous stage about determination of optimum type of bamboo chips in mixture. BLAsh content was varied in the mixtures using 2% of 6 mm bamboo chips as constant type and content of bamboo chips. In addition, percentage of total pozzolanic material is also kept constantly in the amount of 2%. Thus, optimum percentage of BLAsh to replace cement in mixture can be defined.

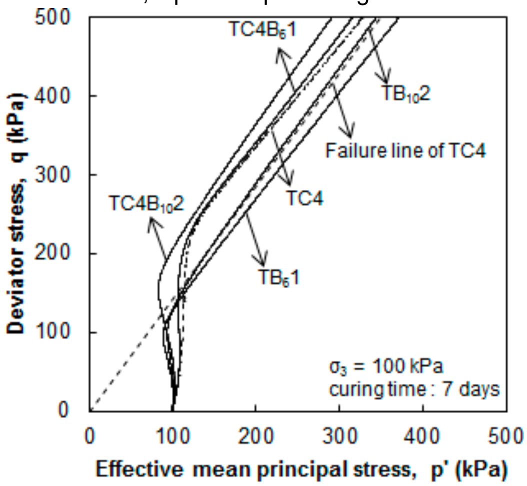


Fig. 17 Stress path in variation of cement.

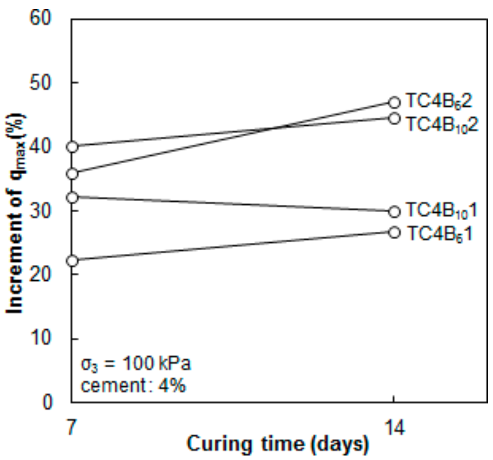


Fig. 18 Increment of maximum deviator stress compared to cemented sand soil.

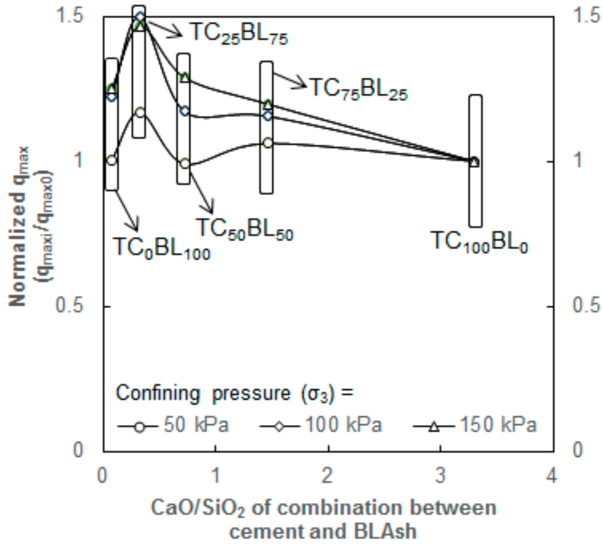


Fig. 19 Result of static triaxial test to the variations of cement replacement by BLAsh.

Tastan et.al. (2011) and Talib et.al. (2015) are two of some literatures that stated the general chemical reaction resulting cementitious and pozzolanic gels (**Equations 1 and 2**). Reaction between cement with H_2O results CSH (calcium silicate hydrates) and $Ca(OH)_2$ (calcium hydroxide). Furthermore, if pozzolanic material is added, $Ca(OH)_2$ is able to react more to result CSH and/or CASH (calcium aluminate silicate hydrate gel). The CSH and CASH have adhesive characteristic that are able to bind particles and harden the mixture. Thus, the additional pozzolanic material provides improvement of cement hydration commonly referred as secondary pozzolanic reaction.

$$\text{Cement} + H_2O \rightarrow CSH + Ca(OH)_2 \quad [1]$$
$$Ca(OH)_2 + \text{pozzolan} + H_2O \rightarrow CSH \text{ and/or } CASH \quad [2]$$

Papadakis (1999) reviewed that in the form of crystalline, Al_2O_3 and Fe_2O_3 are not reactive. However, Villar-Cocina et.al. (2011) mentioned that crystalline minerals was not detected in the BLAsh. Thus, these contents also provide the improvement by its reactivity potential. But, CASH, as the reaction result of Al_2O_3 content shows long-term strength (Tastan et.al., 2011), whereas this investigation focus on the short-term characteristic (7 days curing time). Therefore, in this discussion, SiO_2 becomes the most indicative of increasing strength.

To obtain the optimum content of BLAsh ash as cement replacement, variation of BLAsh was performed. The result of static triaxial test shown by normalized q_{max} (**Fig. 19**). The normalized q_{max} is the ratio between q_{max} of the mixture contains BLAsh with the mixture without BLAsh. The highest normalized q_{max} was reached by mixture $TC_{25}BL_{75}$. The further indicator is shown by the optimum CaO/SiO_2 ratio. To calculate the ratio, each total CaO and SiO_2 content in the mixture is obtained by multiply the percentage combination of each cement and BLAsh material in mixture with CaO and SiO_2 content of each material. The CaO/SiO_2 ratio of the $TC_{100}BL_0$, $TC_{75}BL_{25}$, $TC_{50}BL_{50}$, $TC_{25}BL_{75}$, and TC_0BL_{100} mixture are 3.30, 1.46, 0.72, 0.33, and 0.08, respectively. Based on these results, utilization cement only in the mixture ($TC_{100}BL_0$) and cement replacement in total by cement (TC_0BL_{100}) showed lower result than mixture $TC_{25}BL_{75}$ due to the high CaO and SiO_2 content, respectively. It can be approved that 75% cement replacement by BLAsh is the optimum percentage to increase silica content and improve the strength of the mixture. The increasing strength is about 50% to the original mixture (without BLAsh content). Furthermore, the determination to conclude the optimum mixture by CaO/SiO_2 ratio is more appropriate. By this result, the ratio of about 0.33 is the optimum CaO/SiO_2 ratio in the partially replacement of cement by BLAsh material.

5. Evaluation of environmental impact

5.1 Goal and scope definitions

Goal of this study is to propose BLAsh to partially replace cement in soil improvement as applicable method in field. The intension of this study is to increase the value of bamboo leaf as environmental waste using simple manufacturing process. In this stage, investigation to the effect due to manufacturing process of BLAsh was performed. By this analysis, comparison between BLAsh and cement manufacturing process was investigated to show the effectiveness of BLAsh in production process.

This analysis is limited to the manufacturing process of BLAsh and cement with the purpose of comparing two materials that have same function as pozzolanic materials. In addition, impact assessment focused on CO_2 emission as major direct greenhouse gas emission. This analysis is commonly called as Life Cycle CO_2 ($LCCO_2$).

The following are assumptions used in this study:

(1) Comparison was conducted to the same mass product, i.e. 1 kg mass product.

(2) Information regarding calculation of CO_2 emission based on suggested method by Intergovernmental Panel on Climate Change (IPCC).

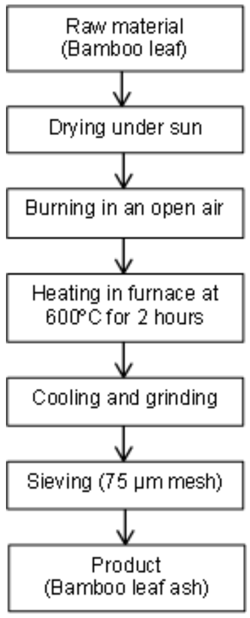


Fig. 20 Flow chart of bamboo leaf ash manufacturing process.

5.2 Life cycle inventory analysis

To determine CO_2 emission, flow chart of manufacturing process of bamboo leaf ash is performed in **Fig. 20**, whereas CO_2 emission calculation of manufacturing process of cement followed standard process commonly applied in cement companies. So, the cement manufacturing process is not performed in this study. However, calculation of CO_2 emission is based on the standard in IPCC (2000). Production process of clinker, as intermediate product in cement manufacture, is the most part that emits CO_2. In addition, CO_2 is also emitted during the calcination of cement kiln dust (CKD). These factors are considered in the calculation of total CO_2 emission of Portland cement production.

In the manufacturing process of BLAsh, bamboo leaf as raw material is waste. So, energy released is at the stage in an open air burning and heating in furnace. In the burning in an open air, fuel is not required. Fire is generated by dried bamboo leaf burning. Complete combustion was conducted until dried bamboo leaf becomes black. The, the burning result was calcined in electrical furnace at 600ºC for 2 hours. This process produces bamboo leaf in grey color. In this process, potential negative environmental impacts may be associated by the calcination process of electrical fuel. The next stages are focused on the changes of physical performance of calcined bamboo leaf, i.e. grinding and sieving. Fuel energy is not required in these both processes, so CO_2 is not emitted. BLAsh is the product passes the 75 µm sieve mesh. The waste byproducts obtained is at a rate about 2% to dry mass of dried bamboo leaf. It still requires investigation regarding its impact to environment before disposing. However, mass

Table 3 Result of CO_2 emission for each process (/1 kg product)

Product	Process	CO_2 emission (kg of CO_2)
Portland cement (PC)	Clinker production	0.487
	Cement Kiln Dust (CKD)	0.029
Total CO_2 emission of PC		0.516
Bamboo leaf ash (BLAsh)	Burning in open air	4.226
	Heating furnace	0.211
Total CO_2 emission of BLAsh		4.437

reduction of bamboo leaf as environmental waste is a good achievement.

5.3 *The impact assessment*

In this study, evaluation of impact to environment by CO_2 emission is calculated for the manufacturing of 1 kg for each BLAsh and cement. The CO_2 emission by transportation during process is not included. However, the calculation of each process that emits most CO_2 during process is considered in detail. The result of CO_2 emission calculation is performed in **Table 3**.

In the production of BLAsh, electrical power was used for heating the burned bamboo leaf. The power of muffle furnace is 1.5 kW at 1100ºC. It is assumed that the power consumption is proportional to the temperature. In this purpose, temperature of furnace was set to 600ºC. Other parameters and correction factors considered in process of clinker production, cement kiln dust, and burning in open air were referred to guidance suggested by IPCC.

5.4 *The interpretation*

The total emission of CO_2 by BLAsh production is about 8.6 times more than Portland cement production that can be seen in **Table 3**. This result is very high value in total. The high CO_2 emission is produced by burning process in open air. It is the reason of the strictly regulation of waste open burning, especially in developed countries. However, developing countries still utilize this method to reduce the volume of bamboo leaf as an agriculture waste directly in the bamboo forest. This activity is able to cut off the manufacturing process of BLAsh by only heating the burned bamboo leaf produced by local bamboo farmer. By this shortened process, the CO_2 emission is only 0.211 kg of CO_2. This value reduces 60% of CO_2 emission by cement production.

However, the high CO_2 emission by open burning process becomes another problem to environment. Carbon sequestration is one of the solutions. This topic is developed in many researches which covers the strategy of carbon management to mitigate the increasing CO_2 emission (Song et al., 2011; Bahtiar et al., 2012; Thokchom and Yadava, 2015). The ability of bamboo trees itself to decrease atmospheric carbon was widely investigated in this topic. By its world record as the fastest growing plant, bamboo is not only able to grow 91cm/day, but also has high potential of carbon sequestration about 57.77-99.81 tCO_2/ha/year (Tariyal, 2016). It becomes naturally cycle of CO_2 emission by bamboo itself. As mentioned before, in the developing country, open burning system is conducted in the bamboo forest directly. By this condition, the passive effort of CO_2 reduction by bamboo tress itself through photosynthesis process is reliable.

For the further investigation, system and analysis of cost consumption commonly referred to as Life Cycle Cost (LCC) of BLAsh utilization is conducted to perform the comprehensive result. Also, other process that is able to replace the open burning process and generate lower CO_2 emission is required.

6. Conclusions

In environmental issues, reduction of cement utilization becomes the main focus in soil improvement. The following conclusions are obtained from this study:

1. Bamboo chips as the environmental-friendly material is proposed to be an additive material in cemented sandy soil by its high water absorbability.
2. Size and content of bamboo chips in cemented sandy soil provides significant result in improvement. 2% of 6 mm bamboo chips showed the optimum size and content by its ability to decrease permeability, improve the dilative behavior and increase the q_{max} of cemented sand soil.
3. BLAsh has high pozzolanic content that can be effectively used as the partially cement replacement cemented bamboo chips-sand soil mixture. As the generalization, CaO/SiO_2 ratio of about 0.33 by 75% BLAsh material that is partially replacing cement is the optimum content to provide highest improvement.
4. In the process of BLAsh production, burning bamboo leaf generates high CO_2. However, bamboo trees itself is reliable to decrease CO_2 by its ability in carbon sequestration.

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