Use of Coal Bottom Ash as Stabilizer Options in Soil Stabilization

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***Abstract*-The study presents the use of coal bottom ash (BA) as stabilizer to improve soft soil property. Coal bottom ash is interesting one of material to applied as stabilizer which has the cementitious property. Unconfined compressive strength (UCS) and California Bearing Ratio (CBR) of stabilized soil was studied under various in BA fineness and curing time. BA was ground to obtain the 7 difference fineness and specimens were cured for 3, 7, 28 and 60 days. The results revealed that the UCS of stabilized soil increase with curing time and fineness. The stabilized soil mixture produced from highest fineness of BA exhibit maximum value for all of curing period. The agreeable result of CBR test reveal the highest value obtained from mixture those having the maximum fineness of BA also. Based on UCS of stabilized soil, the effect of fineness to UCS was classified in 3 zones are non-active zone (fineness less than 4,000 cm^2/g), semi-active zone (fineness between 4,000–6,000 cm^2/g), and active zone (fineness higher than 6,000 cm^2/g). The fineness of BA within range of active zone reveals the highest performance applied to improve soft soil. Correlations between fineness and curing times on compressive strength were evaluated by a multiple regression analysis. XRD analysis result showed that CSH is the major reaction product with contribution to UCS development and CSH was increased with increased in fineness.**

***Keyword:* Bottom ash, Fineness, Pavement materials, Soil stabilization**

I. INTRODUCTION

Soil stabilization is one of the most techniques used to improve the undesirable soft soil properties such as low of shear strength, low of bearing capacity and highly settlement, which is the geotechnical engineering problem. The stabilization process was done by mix the suitable proportion of stabilizer with the soft soil to increase shear strength and bearing capacity consequence in decrease of soil settlement. The basic concept of stabilizers application in geotechnical projects are cementitious materials such as ordinary Portland cement (OPC) because it is a general construction material that is locally available and reasonable price.

Due to OPC is the cost valuable cementitious material, the new thinking of alternative cementitious material was purposed. The interesting one is coal ash from power plant industries. Coal ash was performed by-product of burning coal at electric generation power plant. The clinker was formed after fired and its viscous joining to the hot walls of furnace. Some of the ash that flow up to the chimney is called fly ash (FA) and the remaining was fallen clinker to the bottom of furnace called bottom ash (BA). The particles of BA are larger than FA and various shapes with comparable sizes to fine sand until gravel. Generally, the chemical composition of BA are primary comprise of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and ferric oxide (Fe_2O_3), which can be classified as pozzolanic material in accordance with standard of ASTM C618 [1]. Generally, FA was widely used as stabilizer in soil stabilization more BA because high content of SiO_2 beneficial for cement hydration reaction process. In addition, FA have very fine particle, higher surface particle, that advantage to increase the hydration reaction process [2].

The strength development mechanism of stabilized soil with cementitious material can be explained. When cementitious material is mixed with water within soil mass, the hydration reaction process was formed. The results of that process are primary and secondary reaction products which affect to improved clay cement properties. The primary products are calcium silicates hydrates (CSH), calcium aluminates hydrates (CAH) and lime. The secondary products resulting from the pozzolanic reaction between clay minerals and lime, clay silica and clay alumina were formed as CSH and CAH after continuous in the curing time. Both reaction products resulting in soil mass are denser, stronger and harder, consequence in stabilized soil strength increased with curing time [3]. It was showed that the particle surface area is influence to the rate of hydration reaction process, high particle surface area higher rate of reaction. It is therefore, BA in this study was then ground in difference fineness to increased particle surface area before used.

The purposed of this research is to study the influence of BA fineness on properties of stabilized soil. BA was applied as cementitious materials in difference fineness to produce the stabilized soil sample called soil cement. Unconfined compressive strength (UCS) test was conducted to evaluate strength property and California Bearing Ratio (CBR) test was performed to load-bearing capacity of soil for road pavement. X-ray Diffraction (XRD) analysis was tested to analyzed reaction products of stabilized soil. Correlation between UCS, CBR, reaction products and fineness was evaluated. The use of

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the BA as stabilizer options not only takes advantage of decreased construction costs and creating new materials for engineering construction but also mitigates environmental problems such as air dusting, leaching effect and requirement problem in storage area.

II. MATERIALS AND EXPERIMENTAL PROGRAM

A. Materials

Soil sample used in this study was collected in Bangkok area, Thailand with a depth of 2 to 7 m. from natural ground surface. After laboratory tested, the geotechnical properties of soil as showed in Table I. According to the Unified Soil Classification System (USCS), soil was classified as CH with high plasticity property.

TABLE I
GEOTECHNICAL PROPERTIES OF SOIL

Properties	Value
Natural of water content (%)	93.57
Liquid limit (%)	81.06
Plastic limit (%)	33.67
Plasticity index (%)	47.39
Wet unit weight (kN/m^3)	15.68
Specific gravity	2.63
CBR (%)	1.77
Natural soil strength (kPa)	8-13

BA was sampled from electric generation power plant, Prachinburi province, Thailand. Raw BA was ground by high speed ball mill apparatus to obtain the fineness 2,000, 3,000, 4,000, 5,000, 6,000, 7,000 and 8,000 cm^2/g which then represent by BA20, BA30, BA40, BA50, BA60, BA70 and BA80, respectively. The chemical composition of BA both before and after ground was analyzed by X-Ray Fluorescence (XRF) technique as listed in Table II. The major compound of raw BA comprise of SiO_2, Al_2O_3 and Fe_2O_3 with the other minor compound. BA was classified as a class F of pozzolanic material in accordance with standard of ASTM C618 which the composition summations of SiO_2, Al_2O_3 and Fe_2O_3 higher than 70% by dry weight. The chemical composition of BA was not significant change after ground in difference fineness.

TABLE II
CHEMICAL COMPOSITION OF BA

Com pound	BA in various fineness							
	Raw BA	BA 20	BA 30	BA 40	BA 50	BA 60	BA 70	BA 80
SiO_2	39.82	39.08	39.56	40.07	40.11	39.72	39.65	40.04
Al_2O_3	16.07	15.92	16.22	16.18	15.98	16.04	15.95	15.98
Fe_2O_3	14.15	14.53	14.94	14.09	13.97	14.78	14.42	14.04
CaO	12.78	12.71	12.17	12.59	12.84	12.67	12.68	12.75
MgO	5.15	5.63	5.51	4.96	5.06	5.02	5.24	5.08
SO_3	1.47	1.53	1.43	1.49	1.42	1.46	1.51	1.49
K_2O	2.43	2.29	2.44	2.32	2.49	2.33	2.47	2.38
TiO_2	0.53	0.56	0.49	0.61	0.55	0.57	0.52	0.58
Other	3.57	3.64	3.32	3.61	3.53	3.46	3.51	3.59
LOI.	4.03	4.11	3.92	4.08	4.05	3.95	4.05	4.07

B. Experimental program

In this study, BA various fineness was used as stabilizer for soil stabilization process. According to the research of DOH and JICA [4], the suitable content of stabilizer was within the range 80–200 kg/m^3 of wet soil and a W/B ratio (the ratio of the weight of water to the weight of cementitious material) in a bout of 0.8–1.2. By above the suggestions research, the selected BA content of 200 kg/m^3 of soil and a W/B ratio of 1.0 were applied for all of test.

Soil was mixed with stabilizer in accordance with the JGS T821–1990 [5] standard by using the non-compacted method. The cylindrical specimens, 50 mm diameter and 100 mm long as showed in Fig. 1, were prepared for UCS test with following the standard of ASTM D2166 [6]. After 24 hrs, specimens were de-molding and stored in air with room temperature and cured for 3, 7, 28 and 60 days prior to UCS testing. These storage condition was applied as reflect on the construction site where the stabilized soil are encountered to the climate. Three specimens were prepared from each mixture for each test and each curing period.

According to ASTM D1883 [7], soaked CBR was tested and the average value was done after running by 3 samples. Specimens were compacted in the CBR mold with close to the optimum moisture content with their maximum dry density, corresponding to the test result of untreated soil. Specimens were stored in air with environment temperature and then cured for 7 days. This storage condition was used similar to the specimen preparation for UCS test. After finished 7 days, specimens were soaked 96 hours before test. Soil sample during soak as showed in Fig. 2.

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Figure 1. Stabilized soil sample for UCS test

Figure 2. Soil sample during soak for CBR test

XRD analysis was performed to investigate the reaction products of the stabilized soil. This method was used to consider the correlation between fineness and amount of the reaction product that come from the hydration reaction process. After 7 days of UCS tested, the failure plain of specimen of stabilized soil produced from BA20, BA50 and BA80 was selected to further XRD analysis. The XRD Diffractometer as showed in Fig. 3.

Figure 3. XRD Diffractometer

III. RESULTS AND DISCUSSION

A. Laboratory testing results of UCS and CBR

The UCS development curve of stabilized soil as showed in Fig. 4. It was revealed that UCS increased with time for all mixture of stabilized soil. At initial 3 days, UCS of BA20, BA30, BA40, BA50, BA60, BA70 and BA80 are 156, 171, 178, 224, 247, 264 and 303 kPa, respectively. UCS was increased rapidly from 3 days to 7 days, continuous increased for 28 days and have trend to constant at and 60 days, respectively. BA20, lowest fineness, showed the lowest UCS for all of curing period. BA30, higher in fineness, revealed a little higher of UCS than BA20. BA40 presented higher UCS than BA30 and BTA20, respectively. Development of UCS was clearly increased in BA50, BA60 and BA70 by comparative observing the higher slope in the early age of graph. BA80 having highest fineness was significant showed the highest UCS for all of curing period. It should be stated that the UCS of all stabilized soil mixture was increased with increased in fineness value and curing time.

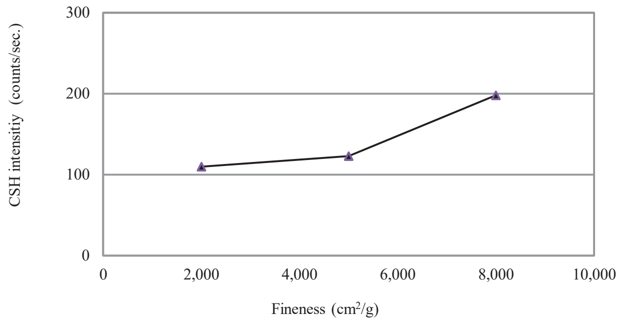

Figure 4. UCS development with curing time

TABLE III
CBR TESTED RESULTS

CBR (%)	BA in various fineness						
	BA 20	BA 30	BA 40	BA 50	BA 60	BA 70	BA 80
	2.35	3.08	3.27	5.04	5.63	7.29	8.62

The CBR of stabilized soil as showed in Table III. The results reveal that all of CBR value increased with increased in fineness. Compare to the original soil, CBR greater than 1.33, 1.74, 1.85, 2.85, 3.18, 4.12 and 4.87 times after stabilized with BA20, BA30, BA40, BA50, BA60, BA70 and BA80, respectively

Relationship between CBR and UCS at the same curing time 7 days was presented in Fig. 5. It was found that CBR values were also increased with an increased in UCS. The relationships reveal the CBR equal to 0.0196 times of UCS approximately after stabilized with BA. Comparison relationships between CBR and UCS for general stabilized soil as showed in Table VI. For the results in this study, the relationships revealed the low values in order to compare with various cementitious stabilized soil. It can be observed that using BA as stabilizer in soil stabilization process was lower efficiency than that the other cementitious materials such as OPC and fly ash. However, using BA was still within general range of relationships value of cement stabilized soil which is CBR = (0.0181-0.0648)UCS.

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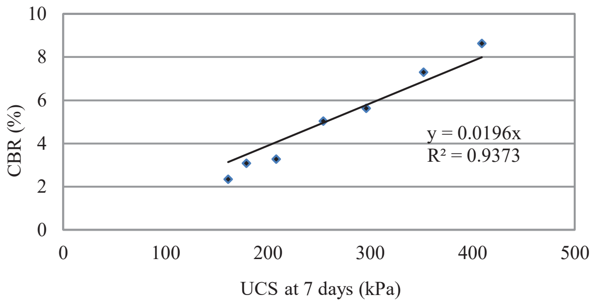

Figure 5. Relationship between CBR and UCS

TABLE VI
RELATIONSHIPS BETWEEN CBR AND UCS FOR GENERAL STABILIZED SOIL

Type of stabilized soil	Relationships	Reference
Fly ash mixed with sandy soil	CBR = 0.0227UCS	[8]
OPC stabilized soft clay	CBR = 0.0343UCS	[9]
Fly ash mixed with lime stabilized soil	CBR = 0.0192UCS	[10]
OPC and locust bean waste ash stabilized black cotton soil	CBR = 0.0224UCS	[11]
Cement kiln dust stabilized cotton soil subgrade	CBR = 0.0648UCS	[12]
OPC and fly ash improved expansive soils	CBR = 0.0181UCS	[13]
Soft highway subgrade soil stabilized with calcium carbide residue	CBR = 0.0423UCS	[14]
BA stabilized soft soil	CBR = 0.0196UCS	This study

B. Influence of fineness incorporation with UCS and CBR

The effect of fineness on UCS with variation of curing time as presented in Fig. 6 reveal the UCS of stabilized soil increased with an increase in curing time and fineness. At the low fineness of 2,000 cm^2/g, 3,000 cm^2/g and 4,000 cm^2/g, it is presented that UCS was a few increasing for all of time which then present by observing in low slope of graph. In the other hand, it can be presented that the low BA fineness was not significant effect to obtain UCS of stabilized soil for all of curing time. After increased fineness 5,000 cm^2/g and 6,000 cm^2/g, rate of gain of UCS was increased higher than sample contained the low fineness of BA, lower than 4,000 cm^2/g. The higher UCS was continued as well as higher in fineness value. The fineness of 6,000 cm^2/g of BA was produced higher UCS than 5,000 cm^2/g. When the fineness higher than 6,000 cm^2/g, rate of gain in strength was clearly increased this can be seen at the fineness of 7,000 cm^2/g. Moreover, the highest of fineness 8,000 cm^2/g produced the maximum UCS in order to compare with other mixture for all of curing time.

The Influence of fineness to UCS development was considered. The smaller particle sizes of BA which have a higher surface area take benefit for the hydration reaction process [15]. When cementitious material (referred as BA) touched with water, the cement hydration reaction was generated all around the surface of the cement particles. The higher fineness of particle this attends to the higher in surface area of cement. Then, the rate of hydration depends on the cement particles fineness and a rapid development of UCS as well as a high fineness is necessary. Therefore, the higher fineness performs the stabilized soil higher reaction hydration product which the majority to produce UCS consequence for development of UCS with time [16].

The effect of fineness was considered in 3 zones are non-active zone, semi-active zone and active zone as showed in Fig. 6. It is to be indicated that the border line of non-active zone is range from 2,000 cm^2/g to 4,000 cm^2/g which present the low fineness have not effect to UCS properties. For semi-active zone, it is present the medium to good fineness zone in relation to increase UCS which then the fineness range from higher than 4,000 cm^2/g to 6,000 cm^2/g. The active zone, the fineness higher than 6,000 cm^2/g to 8,000 cm^2/g, was presented the excellent performance zone to markly increased UCS of stabilized soil.

Similar consideration of fineness effect was done for CBR as showed in Fig. 7. It was found that CBR value was increased with an increased in fineness. At the low fineness of 2,000 cm^2/g, 3,000 cm^2/g and 4,000 cm^2/g, this is showed that the significant change in CBR cannot be observed. After fineness was increased, CBR was also increased and the fineness 8,000 cm^2/g exhibited maximum of the CBR value. The relationships between fineness and CBR agree with the relationships between fineness and UCS. It is therefore, the 3 zones of fineness effect are non-active zone, semi-active zone and active zone was resembled performed.

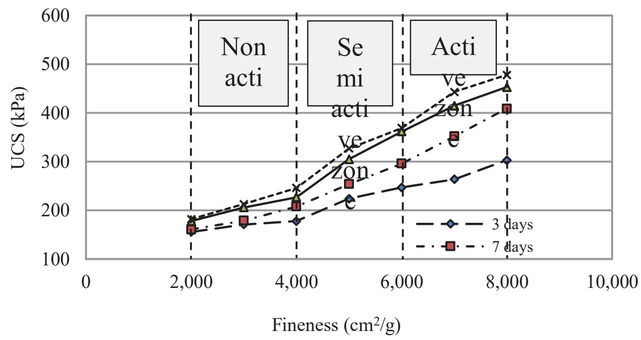

Figure 6. UCS and BA various fineness

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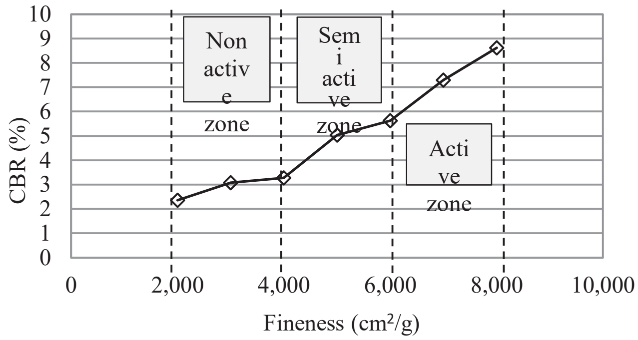

Figure 7. CBR and BA various fineness

C. *Multi-correlations between fineness and UCS for various curing times*

The multi-correlations between fineness and curing times on UCS could be studied by a multiple regression analysis. The multiple regression analysis is an extension technique of simple linear regression to perform relationship between the variable value and dependence predictors.

The multiple regression models were examined to agree well fit for the result of predictor is present in (1) as follows [17].

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \ldots, \; i = 1, 2, 3, \ldots, n \quad (1)$$

From the data of experimental testing results, 28 values of UCS were referred as dependent variable while those the fineness of BA and curing time referred as independent variables. The results equation of multiple regression analysis is as follow in (2)

$$UCS = 30.2743 + 0.0422(Fi) + 1.5372(CT) \quad (2)$$

Where, Fi = fineness of BA in unit of cm^2/g and CT = curing time in unit of day.

According to those proposed equations, the laboratory test and predicted UCS was compared to illustrate by the 95% confidence intervals. Those correlations presented in a good agreement values are 89.49% as showed the comparison of laboratory data and predicted of UCS in Fig. 8.

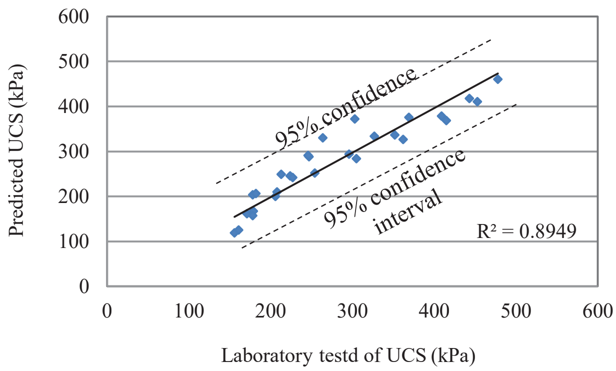

Figure 8. Comparison of laboratory data and predicted of UCS

D. *XRD analysis in relation to UCS and fineness*

The XRD analysis pattern of the natural soil and stabilized soil as showed in Fig. 9. It was found that the natural soil consist of silica form as quartz (Q) and main clay mineral which are montmorilonite (M), illite (I) and kaolinite (K). After stabilized with BA, all sample identifies that the stabilized soil consisted of the major reaction products calcium silicate hydrate (CSH), calcium hydroxide (CH), tri-calcium silicate hydrate (C_3S), di-calcium silicate hydrate (C_2S) together with quartz and clay minerals content such as montmorilonite , illite and kaolinite.

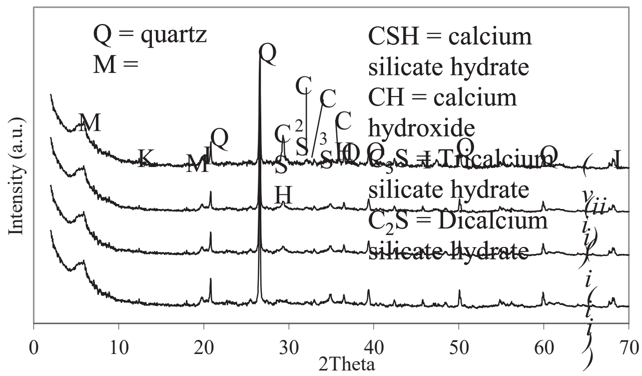

Figure 9. XRD pattern of 7 days of UCS tested, where (i) = natural soil, (ii) BA20 stabilized soil, (iii) BA50 stabilized soil and (vi) BA80 stabilized soil

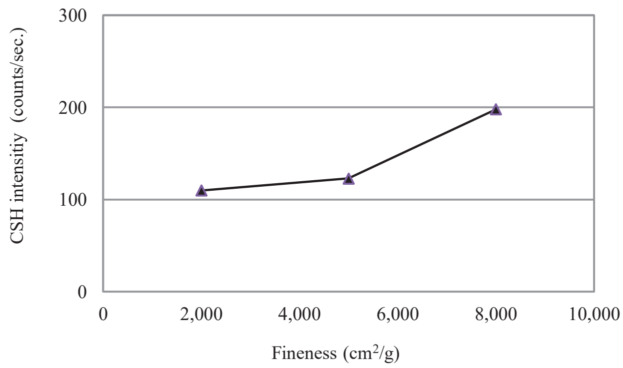

Figure 10. CSH intensity against fineness.

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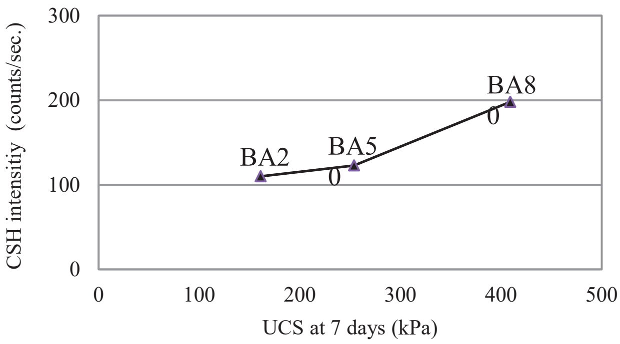

Figure 11. CSH intensity against UCS.

It is well know that the CSH is the main reaction product from hydration process which had an effect on UCS development in cement [18]. In this study, it was found the formation of CSH increased with an increased in BA's fineness as showed in Fig. 10. Similar development trend as showed in Fig. 11 reveal the UCS was increased with CSH and finesses. This is evidence that the BA can be performed the reaction product of CSH and higher CSH resulting in a relatively higher UCS. In addition, the higher CSH can be performed with relation to higher fineness also.

E. Application used for pavement materials

Stabilized soil can be considered as pavement material. There are 5 standards for materials consideration applied as road pavement structure in accordance with the Department of Highways, Thailand and suggestions by [19]. The standard was required the minimum UCS at 7 days for pavement structure as showed in Table V.

Fig. 12 present the conclusion applied the BA stabilized soil as pavement material. It should be noted that the BA20, BA30, BA40 and BA50 is not suitable applied as the subgrade material because the UCS are lower than the above requirement of standard. The BA60 can be used as soil subgrade while those BA70 can be applied as selected material "B". The BA80 exhibit highest UCS at 7 days can be used as selected material "A". Based on the results of pavement material, it is can be stated that the soil cement mixture having fineness in non-active zone and semi active zone was not suitable used as pavement materials. In addition, the soil cements mixture having fineness in active zone present the high potential for application used in road pavement project.

TABLE V
Standard for Pavement Material

Standard	UCS (kPa)
Soil cement base	1,723
Soil cement subbase	689
Selected material "A"	407
Selected material "B"	332
Soil subgrade	294

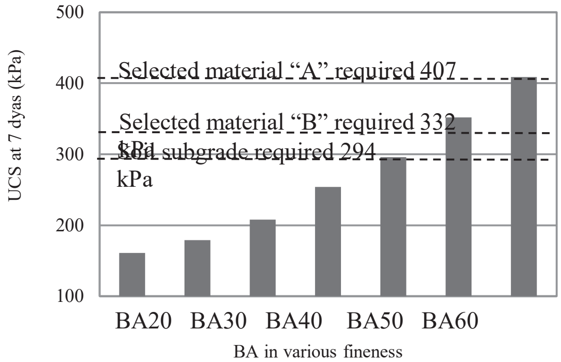

Figure 12. CSH intensity against fineness.

IV. CONCLUSIONS

This study is to investigate the use of bottom ash (BA) as stabilizer options in soil stabilization process. Coal bottom ash was then ground in difference fineness before used. Based on all of tested results, the conclusion of the study are as follow:

(1) Unconfined compressive strength (UCS) and California Bearing Ratio (CBR) of soft natural soil can be improved by coal bottom ash. Stabilized soil strength significantly increases with an increase in fineness and curing time.

(2) The effect of fineness in relation to UCS of stabilized soil was classified in 3 zones are non-active zone (fineness less than 4,000 cm^2/g), semi-active zone (fineness between 4,000 – 6,000 cm^2/g), and active zone (fineness higher than 6,000 cm^2/g). The fineness of bottom ash within range of non-active zone reveal the lowest potential to improve UCS of soil while those the fineness within the active zone present the highest potential to increase UCS of soft natural soil.

(3) XRD analysis result presents the natural soil consist of quartz and main clay mineral which are montmorilonite, illite and kaolinite. The major reaction product of BA stabilized soil is calcium silicate hydrate (CSH) which effect to UCS development. The higher CSH can be performed with relation to higher fineness of BA.

(4) The BA stabilized soil can be used as pavement materials are subgrade, selected material "B" and selected material "A" in order to compare with the fineness of 6,000, 7,000 and 8,000 cm^2/g, respectively.

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