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STRENGTH DEVELOPMENT IN BLENDED CEMENT ADMIXED SALINE CLAY

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Abstract: Cement stabilization is extensively used to improve engineering properties of soft saline clay. The effect of salinity, which is altered with geological and climate changes, on the strength development in cement admixed saline clay is investigated in this paper. For a particular curing time and salt content, the strength development in cement admixed saline clay is governed by the clay-water/cement ratio, w_c/C . The strength increases with the decrease in w_c/C . The increase in salt content for a particular water content causes the increase in generalized stress state, e/e_L where e is the current void ratio and e_L is the liquid limit void ratio. The higher value of e/e_L is associated with the lower effective stress and the inter-particle attraction. Hence, for the same clay-water/cement ratio, the strength of the cement admixed clay with higher salt content is lower than that with lower salt content. From the strength, economic, and environmental points of view, waste ashes (fly ash and biomass ash) can be used to substitute Portland cement. The role of ashes on the strength development of cement admixed saline clay is investigated via unconfined compressive (UC) test and thermogravimetric (TG) analysis. Fly ash and biomass ash are dispersing materials, increasing the reactive surface of the cement grains, and hence strength increases. The clay-water/cement ratio hypothesis is successfully used to analyze and assess the strength development of blended cement admixed saline clay at various salt contents. An addition of 25% ash can save on the input of cement up to 15.8%.

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67 **Keywords:** saline clay, blended cement, clay-water/cement ratio, unconfined compressive

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1. INTRODUCTION

Northeast Thailand covers more than one-third of the country of 16.9 million ha with 9.25 million ha of agricultural land or 44% of the arable land in the country. There is about 2.8 million ha of saline soil or 17% of the total area in northeast Thailand. The soils are classified as severe, moderate and slight areas of 240,000, 590,000 and 2,020,000 ha, respectively (Yuvaniyama et al., 2005). The surface salinity originates from the rock salt beads of the Mahasarakam Formation of the Mesozoic Khorat Group. For wet lands, flood plains and lowlands, the saline soil is generally saturated and soft clay deposits. Its salinity is changed with time due to climate and geological changes. This soft saline clay possesses high compressibility and low shear strength. One of the extensively used soil improvement techniques is the in-situ cement stabilization such as shallow and deep mixing. This technique is economical because cement is readily available at reasonable cost in Thailand. Moreover, adequate strength can be achieved in a short time.

The fundamental mechanical characteristics of cement admixed clays have been experimentally and numerically investigated by many researchers (Terashi, 1979; Kawasaki et al., 1981; Kamon and Bergado, 1992; Horpibulsuk et al., 2004a and b and 2010a; and Suebsuk et al., 2010 and 2011). These investigations mainly focused on the influence of water content and cement content. The combination effect from both water content and cement content is integrated by the clay-water/cement ratio (Horpibulsuk and Miura, 2001; Horpibulsuk et al., 2005; and Miura et al., 2001). The clay-water/cement ratio, w_c/C is defined as the ratio of clay water content to cement content (both reckoned in percentage). While the clay water content reflects the microfabric of soft clay, the cement content influences the level of bonding of that fabric. Based on this parameter and Abrams' law (Abrams' 1918), Horpibulsuk et al. (2003) introduced a phenomenological model for predicting laboratory

strength development in cement admixed clays at various water contents, cement contents and curing times. This model was refined to develop a generalized strength equation for cement admixed non- to low swelling clays (Horpibulsuk et al., 2011b).

For engineering, economic and environmental impacts, the replacement of the cement by waste materials such as fly ash and biomass ash is highly attractive and valuable. In Thailand, the generation of these waste materials is general far in excess of their utilization. A feasibility study of utilizing these ashes (waste materials) to partially replace Type I Portland cement is thus significant. The role of fly ash on the strength development in the blended cement admixed clay was investigated both from macro- and micro-observations (Horpibulsuk et al., 2009; and Horpibulsuk and Raksachon, 2010). Unlike in concrete (with required 28-day strength generally higher than 28 MPa), fly ash in cement admixed clays (required 28-day strength only 600-3000 kPa) does not act as the pozzolanic material because of the low Ca(OH)_2 from hydration to be reactive with. When the soft clay is mixed with cement, the clay and cement particles group together into large clay-cement clusters due to physicochemical interaction (Horpibulsuk et al., 2010b). Fly ash disperses large clay-cement clusters into smaller clusters. The dispersion leads to the increase in the reactive surface, and hence strength enhancement. Particle size of the fly ash influences insignificantly the dispersing effect.

The dispersing effect can be regarded akin as an addition of cement. By considering that the ash content can be equivalent to cement content, the clay-water/cement ratio hypothesis for blended cement admixed clay (Horpibulsuk et al., 2011a) was developed as follows: "For given set of blended cement admixed clay samples, the strength development depends only on the clay-water/cement ratio, w_c/C , where the total cement content (C) is the sum of input of cement (C_i) and equivalent cement content (C_e)". The equivalent cement content (C_e) is equal to ka where k is dispersing factor and a is ash content. Because the

pozzolanic reaction is minimal, the C_e is mainly dependent upon the dispersing effect, governing by the ash content and alters insignificantly with curing time. In other words, the k -value is practically constant with curing time for a given combination of cement content and ash content. The thermogravimetric (TG) analysis showed that the cementitious products of the blended cement admixed clay samples are practically the same as long as the w_c/C is the same. Based on the Abrams' law and the clay-water/cement ratio hypothesis for blended cement admixed clay, the strength equation was proposed:

$$q_u = \frac{A}{\left(\frac{w_c}{C_i(1+ka)} \right)^B} \quad (1)$$

where q_u is the compressive strength of blended cement admixed clay at a specific curing time, w_c is clay water content, A and B are empirical constants. The three parameters A , B and k for different curing times can be determined from a multi-regression analysis (MRA). The A -value increases with curing time and is mainly dependent upon the clay type. For non- to low-swelling clays, the B -value is almost constant, being equal to 1.27. The k -value is independent of curing time and ash type. It is about 0.75 for blended cement admixed Bangkok clay. When $a = 0\%$ (no ash), Eq.(1) becomes that developed for the cement admixed clays (without ash) by Horpibulsuk et al. (2011b).

Even with available literature on engineering properties of cement admixed clays, the investigation of the effect of salinity on the engineering properties is very limited. The change in the pore water chemistry, caused by the salinity change, leads to a modification of the basic clay-water interaction and affects both the physical and engineering properties of remolded clay. Horpibulsuk et al. (2011c) showed that the generalized stress state, e/e_L (where e is void ratio and e_L is liquid limit void ratio) is a useful parameter to interpret the intrinsic engineering properties when their pore medium chemistry is changed. As the e/e_L decreases, both effective stress and shear resistance of the remolded clays increase.

The present paper attempts to investigate the effect of salt content on index properties of saline clay to explain strength development in cement admixed saline clay. The possibility of using the clay-water/cement ratio hypothesis to analyze the strength development in blended cement admixed saline clay is examined. The empirical constants B and k for different salt contents are investigated. The B - and k -values obtained from the present work and previous works (Horpibulsuk et al., 2003; 2011a and b) are analyzed to develop a generalized strength equation for different blended cement admixed clays. Two blended cements were used in this study, which are the fly ash blended cement and the biomass ash blended cement. The role of the ashes on the cementitious products and the strength development is illustrated by the thermogravimetric analysis and unconfined compression test. This study and the generalized strength equation can be fundamental for analyzing and assessing the strength development in the other blended cement admixed clays.

2. LABORATORY INVESTIGATION

2.1 Soil Sample

Soil sample was collected from Phimai district, Nakhon Ratchasima, Thailand at a 2 meter depth. Phimai clay is saline alluvium that sits over residuum derived from the grained sedimentary rock. Phimai clay is classified into Typic Natraqualfs subgroup according to soil taxonomy. The soil sample is composed of 17% sand, 45% silt and 38% clay. Its specific gravity is 2.65. The liquid and plastic limits are in the order of 43 and 24 percent, respectively. Groundwater was at about 1 m below the ground surface. Natural water content was 39 percent, which is close to liquid limit. Based on the Unified Soil Classification System (USCS), the clay is classified as low plasticity (CL). The free swell test proposed by Prakash and Sridharan (2004) showed that the clay is classified as low-swelling type with free swell ratio (FSR) of 1.3. The FSR is defined as the ratio of equilibrium sediment volume of 10 g of

oven-dried soil passing a 425 μm sieve in distilled water (V_d) to that in kerosene (V_k). This method was employed because it is simple and predicts dominant clay mineralogy of soils satisfactory (Horpibulsuk et al., 2007). Chemical composition and grain size distribution curve of the clay are shown in Table 1 and Figure 1, respectively. The SEM photo of the saline clay is shown in Figure 2. This clay has electrical conductivity, EC_e of 26 dS/m, sodium adsorption ratio, SAR of 3.34. With very high EC_e (higher than 15), this soil is classified as very strongly saline and dispersive (US Salinity Laboratory Staff, 1995).

Figure 1: Grain size distribution curves of Bangkok clay, PC, FA, and BA.

Figure 2: SEM photos of saline clay, PC, FA, BA.

Table 1: Chemical composition of saline clay.

3.2 Cement, Fly Ash, and Biomass Ash

Type I Portland cement (PC), fly ash (FA) from Mae Moh power plant in the north of Thailand and biomass ash (BA) from Thai Power Supply Company Limited in Chachoengsao province were used in this study. Chemical composition obtained from X-Ray Fluorescence (XRF) analysis of PC, FA and BA is given in Table 2. Both FA and BA were passed through sieve No. 325 to remove larger particles. Total amount of the major components SiO_2 , Al_2O_3 and Fe_2O_3 in FA and BA are 79.44% and 75.57%, respectively. FA is classified as class F fly ash in accordance with ASTM C 618 whereas BA is referred to as “off-specification” because it meets neither the class C nor class F criteria. Grain size distribution curves of PC, FA, and BA are also shown in Figure 1. These curves were obtained from the laser particle size analysis. Specific gravities of PC, FA and BA are 3.15, 2.54, and 1.95, respectively. SEM

photos of PC, FA and BA are also shown in Figure 2. The PC and BA particles are irregular in shape whereas the FA particles are spherical.

Table 2: Chemical composition of PC, FA and BA.

3.3 Methodology

The saline clay was passed through a 2-mm sieve to remove coarser particles. The clay was submerged for a week to dissolve the salinity and was mixed with salt to attain salt contents of 0.075, 1.3, 3, 5, 10 and 15% dry weight of clay. The salt was obtained from a salt field in Phimai area. Its composition is shown in Table 3. NaCl is the main composition with the content of 95.5%. The index tests were performed on the saline clay samples at different salt contents according to the American Society for Testing and Materials (ASTM) standard. The test was performed to illustrate the effect of salt content on index properties of saline clay to explain the strength development in cement admixed saline clay.

The role of salt content and ash content on the strength development is investigated based on the unconfined compression test results. The water contents of the samples with different salt contents were adjusted to the range of liquidity indices (I_L) i.e., 1.0, 1.5, and 2.0. The liquidity index was used in this investigation as an indicator to refer the initial water content of the clay in relation to plasticity characteristics before cement is admixed as has been done by Horpibulsuk et al. (2003, 2011a and b) and Miura et al. (2001). This intentional increase in water content is to simulate water content increase, taking place in wet method of dispensing cement admixture in deep mixing. The clay samples with their water content, corresponding to the above levels of I_L were thoroughly mixed with the blended cements (PC+FA and PC+BA). Cement content, C_i , varied from 0 to 30%, which is commonly used

for the improvement of high water content clay (Horpibulsuk et al., 2003 and 2011a and b). FA and BA contents, a , varied from 0 to 60% by weight of cement. The mixing time was arbitrarily fixed at 10 min as recommended by Miura et al. (2001); and Horpibulsuk et al. (2003). Such a uniform paste was transferred to cylindrical containers of 50 mm diameter and 100 mm height, taking care to prevent any air entrapment. After 24 hours, the cylindrical samples were dismantled. All the cylindrical samples were wrapped in vinyl bags and stored in a humidity room of constant temperature ($20\pm 2^\circ\text{C}$) until lapse of different curing times as planned. Unconfined compression (UC) tests were run on samples after 7, 14, 28, 60 and 90 days of curing. The rate of vertical displacement in UC tests was 1 mm/min.

To examine the possibility of the clay-water/cement ratio hypothesis, the capability of the w_c/C as a prime parameter in analyzing the stress-strain response and strength development in saline clay must be proved. The unconfined compression (UC) tests on the samples having the same w_c/C for different water contents were carried out. The w_c/C values of 3, 5 and 10 at 28 days of curing were considered. The role of ash as dispersing material on the growth of cementitious products was illustrated by the thermogravimetric (TG) analysis. The blended cement admixed samples were broken from the center into small fragments. The samples were frozen at -195°C by immersion in liquid nitrogen for 5 minutes and evacuated at a pressure of 0.5 Pa at -40°C for 5 days (Horpibulsuk et al., 2009 and 2010b). Prior to TG testing, the dried samples were ground in a ball mill and sieved through 100 mesh (150 μm). Approximately 10-20 mg of the sample was taken for the analysis. The heat rate was maintained at $10^\circ\text{C}/\text{min}$ and the sample was heated up to $1,000^\circ\text{C}$. When heating the samples at temperature between 450 and 580°C , $\text{Ca}(\text{OH})_2$ is decomposed into calcium oxide (CaO) and water (Midgley, 1979; El-Jazairi and Illston, 1977 and 1980; and Wang et al., 2004) as in Eq. (2).

Due to the heat, the water is lost, leading to the decrease in overall weight. The amount of Ca(OH)_2 can be approximated from this lost water by Equation (2), which is 4.11 times the amount of lost water (El-Jazairi and Illston, 1977 and 1980). The change of the cementitious products (hydrated calcium silicates, hydrated calcium aluminates and hydrated calcium aluminium silicates) can be expressed by the change of Ca(OH)_2 because they are the hydration products. Horpibulsuk et al. (2009, 2010b and 2011a and b) have successfully used this technique to approximate the Ca(OH)_2 of the cement admixed clay for explaining the growth of cementitious products and strength development.

Finally, a generalized strength prediction equation for the blended cement admixed saline clay for different salt contents is suggested based on the clay-water/cement ratio hypothesis. It is a very useful tool for mix design. The proposed equation was verified by the separate test results of the BA blended cement admixed saline clay for different water contents ($w_c = 43$ to 62%), cement contents ($C = 10$ to 30%) and ash contents ($a = 10, 15$ and 25%).

4. TEST RESULTS

4.1 Strength Development in Cement Admixed Saline Clay

Figure 3 shows the influence of salt content on the index properties of the saline clay samples. As the salt content increases, both liquid limit and plastic limit decrease; hence the decrease in plasticity index. The decrease in liquid limit is due to the reduction in thickness of diffusion double layer. Even with the change in liquid limit and plastic limit, the relationship between plasticity index, I_p and liquid limit, w_L of all saline clay samples still lies above A-line as shown in Figure 4. Since I_p and w_L relation is unique for all saline clay samples, either I_p or w_L can be used to explain the change in their intrinsic engineering properties with salt content. In this study, the liquid limit, which is widely used in correlating index properties to

intrinsic properties (Nagaraj et al., 1998; and Burland, 1990; and Liu and Carter 1999; and Horpibulsuk et al., 2007; and Horpibulsuk et al., 2011c), is taken.

The strength development in saline clay samples at the same clay-water/cement ratio (same water content and cement content, $w_c = 53\%$ and $C = 20\%$) but different salt contents is shown in Figure 5. As the salt content increases, the strength decreases. The presence of the salt affects the generalized stress state e/e_L of the saline clay. For a particular water content, the generalized stress state e/e_L decreases with the salt content due to the decrease in liquid limit; therefore, the effective stress (inter-particle attraction) of cement admixed saline clay decreases. This causes the decrease in strength of cement admixed saline clay.

Figure 6 shows the typical stress-strain relationships in unconfined compression tests of saline clay samples for different initial water contents and cement contents but the same w_c/C values of 3, 5, and 10 and salt content of 1.3%. It is noted that the w_c/C is the prime parameter governing the strength development when the salt content is the same. As the w_c/C decreases, the strength increases due to the stronger cementation bond. The similar stress-strain behavior of all the admixed samples, having the same w_c/C values, is figured out. It is concluded from these results that the strength of cement admixed saline clay is controlled by both the clay-water/cement ratio and the salt content.

Figure 4: Relationship between I_p and w_L of the saline clay for various salt contents.

Figure 5: Strength development with time of the saline clay for various salt contents.

Figure 6: Role of w_c/C on the strength development in the saline clay for different water contents and cement contents.

4.2 Role of Fly Ash on Strength Development

The typical strength development with ash content for the FA blended cement admixed saline clay is shown in Figure 7, which is for 53% water, 20% cement and 28 days of curing. Both the strength and unit weight increase with fly ash content and achieve the peak values at $a = 25\%$. They decrease gradually with the ash content when $a > 25\%$. The fly ashes in excess of 25% possibly surround the cement grains and obstruct the interaction between water and cement grains. Consequently, the cementitious products decrease and hence the reduction in strength when $a > 25\%$. This characteristic is the same as that of the FA and BA blended cement admixed Bangkok clay reported by Horpibulsuk et al. (2011a). The optimal ash content is 25% and independent of cement content because the ash content is determined in proportion to the cement content.

The role of ash on the strength development is illustrated by the growth of cementitious products as shown in Table 3. It shows the amount of Ca(OH)_2 for the FA blended cement admixed saline clay at 53% water for different cement contents and fly ash contents. For the range of ash content tested ($a \leq 25\%$), the amount of Ca(OH)_2 for all the blended cement admixed samples is higher than that of the cement admixed sample (without fly ash). This higher amount of Ca(OH)_2 is associated with the higher strength for the blended cement admixed clay. In contrast, for fly ash concrete, the strength increase due to pozzolanic reaction is associated with the reduction in Ca(OH)_2 (Chindaprasirt et al., 2004 and 2006; and Sinsiri et al., 2006). This result confirms that the pozzolanic reaction is minimal for the blended cement admixed clay. The contribution of the ash to the strength development is mainly dispersing effect.

Figure 7: Relationship between strength and unit weight versus fly ash content.

Table 3: $\text{Ca}(\text{OH})_2$ of the FA blended cement admixed saline clay for different cement contents and fly ash contents at 28 days of curing time.

Based on Eq.(1), the analysis of strength development for the effective dispersing range ($a \leq 25\%$) is performed and shown in Figure 8 and 9. The generalized two-dimensional q_u-w_c/C plots for the FA and BA blended cement admixed saline clay with 1.3% salt at different curing times are shown. Similarly, the role of salt content on the strength development is illustrated in Figure 10 for 7 and 28 days of curing. It is clear that the clay-water/cement ratio hypothesis can be applied to cement admixed saline clay with a wide range of salt content. The variation of parameter A is marked and is dependent on curing time and salt content. The strength of cement admixed saline clay decreases with salt content; therefore, the A -value decreases as the salt content increases. The values of B and k are practically identical for both the blended FA and BA admixed saline clay and irrespective of water content, cement content, ash content and curing time. The variations of parameters B and k are very small, which are between 1.25 and 1.27 and 0.74 and 0.78 for both the FA and BA blended cement admixed saline clay. On the contrary, the k -value of the fly ash concrete increases significantly with curing time (Papadakis and Tsimas, 2002). It is concluded from the present work and the previous works (Horpibulsuk et al., 2009; 2011a and b) that the dispersing effect is independent of salt content and shape and grain size of the ashes. The B - and k -values can be taken as 1.27 and 0.75 for non- to low-swelling clays.

Figure 8: Relationship between strength and clay-water/cement ratio for FA blended cement admixed saline clay.

Figure 9: Relationship between strength and clay-water/cement ratio for BA blended cement admixed saline clay.

Figure 10: Relationship between strength and clay-water/cement ratio of FA blended cement admixed saline clay for various salt contents.

From Eq.(1), at a particular curing time, the strength ratio at different clay-water/cement ratio is proposed as follows:

$$\frac{q_{(w_c/C)_1}}{q_{(w_c/C)_2}} = \left[\frac{(w_c/C)_2}{(w_c/C)_1} \right]^{1.27} \quad (3)$$

where $q_{(w_c/C)_1}$ is the strength to be estimated at clay-water/cement ratio of $(w_c/C)_1$ and $q_{(w_c/C)_2}$ is the strength value at clay-water/cement ratio of $(w_c/C)_2$. From the above equation, it is possible to assess the strength at any other clay-water/cement ratio (clay-water content, cement content and fly ash content).

4.3 Strength Development with Curing Time

The typical strength development with curing time is shown in Figures 11 and 12 for the FA and BA blended cement admixed saline clay with 1.3% salt, respectively. It is noted that strength development with curing time (days) in natural logarithmic scale can be expressed as linear variation. It is evident that at a particular w_c/C , the strength development with time is controlled by the A -value only because the B - and k -values for all practical purposes can be regarded as constant. Even though the A -values are different for different salt contents, the rate of strength development with time is identical because the cementitious products influence the rate predominantly. The generalized strength development for the FA and BA blended cement admixed saline clay is presented in the form (*vide* Figure 13):

$$\frac{q_D}{q_{28}} = 0.099 + 0.281 \ln D \quad (4)$$

where q_D is the strength after D days of curing, q_{28} is the 28 day-strength and D is the curing time (days). This generalized strength development is close to that proposed for cement

admixed clays (with and without ashes) (Horpibulsuk et al., 2003; and 2011a and b). It accounts for the effects of clay water content, cement content and ash content.

Figure 11: Strength development with time for the FA blended cement admixed saline clay.

Figure 12: Strength development with time for the BA blended cement admixed saline clay.

Figure 13: Generalized strength development for the FA and BA blended cement admixed saline clay.

5. INTERRELATIONSHIP AMONG STRENGTH, CLAY-WATER/CEMENT RATIO AND CURING TIME

Because the clay-water/cement ratio hypothesis is valid for cement admixed saline clay, the generalized strength equation can be developed in the same way as for the original one (Horpibulsuk et al., 2011a). The generalized interrelationship among strength, curing time and w_c/C for assessing strength development of the blended cement admixed saline clay in which the w_c/C ranges from 1 to 6 is expressed by combination of Equations (3) and (4).

$$\left\{ \frac{q_{(w_c/C)_D}}{q_{(w_c/C)_{28}}} \right\} = \left[\frac{(w_c/C)_{28}}{(w_c/C)_D} \right]^{1.27} (0.099 + 0.281 \ln D) \quad (5)$$

where $q_{(w_c/C)_D}$ is the strength of the blended cement admixed saline clay to be estimated at clay-water/cement ratio of $(w_c/C)_D$ after D days of curing and $q_{(w_c/C)_{28}}$ is the strength of the blended cement admixed saline clay at clay-water/cement ratio of (w_c/C) after 28 days of curing and

$$C = C_i (1 + 0.75a) \quad (6)$$

In this development of the interrelationship, the k value of 0.75 is considered for $a \leq 25\%$. Using Eq. (5), the assessment of the strength development in the BA blended cement admixed saline clay with 1.3% salt is presented in Table 4 as an example. The 28-day strength of the sample made up at $w_c = 43\%$, $C = 20\%$ and $a = 10\%$ was taken as a reference. The error from the prediction is acceptable for engineering practice with the mean absolute percent error less than 8.2%. This reinforces the applicability of the proposed relationship. The expression proposed is simple within the framework of Abrams' law and requires the strength data of a trial mix. Based on the previous researches (Horpibulsuk et al., 2011a and b) and the present work, it is concluded that equation (5) is valid for low-swelling clays with a wide range of salt content. The B - and k -values can be taken as 1.27 and 0.75, respectively. The equation requires only a laboratory strength value of the cement admixed clay (with or without fly ash and biomass ash) for a particular curing time and mixing condition (water content and cement content).

An addition of 25% ash is recommended for an economic mix design. By substituting $a = 25\%$ in Eq.(6), the economic input of cement for the blended cement admixed clay in terms of the total equivalent cement is $C_i = 0.842C$. This recommended mix design can save on the input of cement up to $15.8\% \left[\left(\frac{1-0.842}{1} \right) \times 100\% \right]$.

Table 4: Strength prediction of the BA blended cement admixed Bangkok clay.

6. CONCLUSIONS

This paper deals with the analysis and assessment of strength development in the blended cement admixed saline clay. The clay-water/cement ratio hypothesis is extended for this study. The following conclusions can be advanced from this study.

1. The presence of salt content affects the index properties of saline clay. The liquid limit decreases as salt content increases due to the decrease in the thickness of diffusion double layer. For a particular water content, the generalized stress state e/e_L increases as the salt content increases. This causes the reduction in the effective stress (inter-particle attraction) and shear strength of the saline clay.
2. The strength development in cement admixed saline clay is dependent upon the salt content and clay-water/cement ratio. The clay-water/cement ratio hypothesis is applicable for analyzing and assessing the strength development in cement admixed saline clay. For the cement admixed saline clay samples with different salt contents but the same clay-water/cement ratio, the samples with lower salt content exhibits higher strength due to the lower generalized stress state, e/e_L .
3. Due to the dispersing effect, fly ash and biomass can be used to reduce the input of cement. The 25% ash content is the most effective amount and can save cement up to 15.8% for achieving the same strength. The strength test results and thermogravimetric analysis show that this ash content yields highest cementitious products and strength. This dispersion increases the reactive surface for hydration and hence cementitious products and strength.
4. Based on the present work, a generalized strength equation for blended cement admixed non- to low swelling clays is suggested. The B - and k -values can be taken as 1.27 and 0.75 for all curing times. The equation facilitates the determination of proper

quantity of blended cement to be admixed for different in-situ and field mixing water contents. The formulation of the proposed relationship is on sound principle.

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Figure 1: Grain size distribution of saline clay, fly ash, biomass ash and Portland cement.

Figure 2: SEM photos of saline clay, fly ash, biomass ash and Portland cement Type I.

Figure 3: Index properties of saline clay for various salt contents.

Figure 4: Relationship between I_p and w_L of the saline clay for various salt contents.

Figure 5: Strength development with time of the saline clay for various salt contents.

Figure 6: Role of w_d/C on the strength development in the saline clay for different water contents and cement contents.

Figure 7: Relationship between strength and unit weight versus fly ash content.

Figure 8: Relationship between strength and clay-water/cement ratio for FA blended cement admixed saline clay.

Figure 9: Relationship between strength and clay-water/cement ratio for BA blended cement admixed saline clay.

Figure 10: Relationship between strength and clay-water/cement ratio of FA blended cement admixed saline clay for various salt contents.

Figure 11: Strength development with time for the FA blended cement admixed saline clay.

Figure 12: Strength development with time for the BA blended cement admixed saline clay.

Figure 13: Generalized strength development for the FA and BA blended cement admixed saline clay.

Figure Captions

Figure 1: Grain size distribution curves of Bangkok clay, PC, FA, and BA.

Figure 2: SEM photos of Bangkok clay, cement, FA, and BA.

Figure 3: Strength development with fly ash content for different water contents.

Figure 4: Strength development with fly ash content for different cement contents.

Figure 5: Analysis of strength development in the FA blended cement admixed Bangkok clay using the clay-water/cement ratio hypothesis.

Figure 6: Analysis of strength development in the BA blended cement admixed Bangkok clay using the clay-water/cement ratio hypothesis

Figure 7: Compression behavior of the FA blended cement admixed Bangkok clay samples, having the same w_c/C .

Figure 8: Stress-strain relationship of the FA blended cement admixed Bangkok clay samples, having the same w_c/C under unconfined compression test.

Figure 9: Strength development in the FA blended cement admixed clay.

Figure 10: Strength development in the BA blended cement admixed clay.

Figure 11: Generalized strength development for FA and BA blended cement admixed Bangkok clay.