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Assessment of strength development in blended cement admixed Bangkok clay

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ABSTRACT

Fly ash and biomass ash have been widely accepted as waste materials substituting Portland cement. In this paper, the role of these two ashes on the strength development of cement admixed low-swelling Bangkok clay is investigated via unconfined compressive (UC) test and thermal gravity (TG) analysis. Fly ash and biomass ash are dispersing materials, increasing the reactive surface of the cement grains. The pozzolanic reaction does not play any significant role on the strength development with time since the amount of $Ca(OH)_2$ is insufficient to react with the ashes. The contribution of the dispersing effect to the strength development is regarded akin as an addition of cement. Based on this premise, the clay–water/cement ratio hypothesis for blended cement admixed clay is proposed for analyzing and assessing the strength development. Even with the difference in water content, cement content and ash content, the blended cement admixed clay samples having the same clay–water/cement ratio, w_c/C possess practically the same stress–strain response and strength. The relationship among strength, clay–water/cement ratio, and curing time for the blended cement admixed Bangkok clay is finally developed and verified. It is useful to assess the strength at any curing time wherein water content, cement content, and ash content vary over a wide range by using the test result of a single laboratory trial. For the economic mix design (the most effective dispersing effect), an addition of 25% ash is recommended. It can save on the input of cement up to 15.8%.

1. Introduction

Bangkok clay is one of the well-known soft clay deposits. It possesses high water content close to its liquid limit with large potential for settlement and low inherent shear strength. This clay is classified as non- to low swelling whose swelling potential increases with depth [1]. Besides Bangkok clay, non- to low swelling soils are generally found in many lowlands such as Ariake, Pusan, Singapore, Drammen, Louiseville clays [2–4]. Even though clay mineralogy of many clayey soils is primarily montmorillonite, montmorillonite in those soils might not be a dominant parameter, controlling the soil expansivity. The other parameters such as other clay minerals (kaolinite, illite, etc.), non-clay fraction (>0.002 mm) and pore medium chemistry can also play a great role, masking the role of montmorillonite. As such, it is possible that some clayey soils can be classified as non-swelling or low swelling type, even though their primary clay mineral in clay fraction (<2 μm) is montmorillonite [1].

One of the effective soft ground improvement techniques is in situ deep mixing (DM). The DM method has been developed during last over two decades primarily to effect columnar inclusions into the soft ground to transform such whole soft ground to composite ground. It has been applied popularly and successfully in Southeast Asia. The DM technology was simultaneously developed in Sweden and Japan using the quicklime as the hardening agent. Later on, normal Portland cement slurry was used. In Thailand, Portland cement is commonly used as a cementing agent since it is readily available at reasonable cost. The influential factors, controlling field strength development of deep mixing columns, were investigated by Horpibulsuk et al. [5] (Ariake clay, Japan) and Horpibulsuk et al. [6] (Bangkok clay, Thailand).

The fundamental mechanical properties of cement admixed clays have been experimentally investigated by many researchers [7–10]. These investigations mainly focus on the influence of water content and cement content on the mechanical properties. The combination effect from both water content and cement content was however not well integrated. Clay–water/cement ratio, which is the ratio of clay water content to cement content (both reckoned in percentage) has been found to meet the above need [11–13]. While the clay water content reflects the micro-fabric of soft clay, the cement content influences the level of bonding of that fabric.

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Based on this parameter and Abrams' law [14], Horpibulsuk et al. [15] have introduced a phenomenological model for predicting laboratory strength development in cement admixed clays at various water contents, cement contents, and curing times. This model has been refined to develop a generalized strength equation for cement admixed non- to low swelling clays [6].

To reduce the construction cost of the DM method, the replacement of the cement by waste materials such as fly ash and biomass ash is one of the best alternative ways. 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 in DM method is thus interesting. Fly ash has been long known as a waste pozzolanic material for concrete structure. When the pore water of the aggregates encounters with cement, the cement hydration occurs rapidly. The major hydration products are hydrated calcium silicates (CSH), hydrated calcium aluminates (CAH), hydrated calcium aluminium silicates (CASH) and hydrated lime ($Ca(OH)_2$). This hydration leads to a rise of pH value of the pore water, which is caused by the dissociation of $Ca(OH)_2$. The strong bases dissolve the silica and alumina from the pozzolanic materials, in a manner similar to the reaction between a weak acid and strong base. The hydrous silica and alumina will then gradually react with the calcium ions liberated from the hydrolysis of cement from insoluble compounds (secondary cementitious products), which hardens with time.

Application of fly ash for geotechnical works has been reported by many researchers [16–18]. The role of fly ash on the strength development in the blended cement admixed clay has been investigated both from micro- and micro observations [19,20]. Unlike in concrete (with required 28-day strength generally higher than 28 MPa), fly ash in cement admixed clays (required 28-day strength only 0.6–3 MPa) does not act as the pozzolanic material because of the low $Ca(OH)_2$ from hydration to be reactive with. Fly ash disperses large clay–cement clusters formed due to physicochemical interaction into smaller clusters. The dispersion leads to the increase in the reactive surface, and hence strength enhancement. Horpibulsuk et al. [19] have demonstrated that particle size of the fly ash insignificantly influences the dispersing effect.

The present paper attempts to analyze and assess the laboratory strength development in the blended cement admixed Bangkok clay. Two blended cements were used in this study, which are the fly ash blended cement and the biomass ash blended cement. The role of both the ashes on the cementitious products and the strength development is illustrated. The growth of cementitious products is examined by the thermal gravity analysis. The method of assessing the strength development is finally developed and verified. The clay–water/content ratio hypothesis [11–13] is extended for this development. This method is possibly applied to the other cement admixed non- to low swelling clays for different construction works.

2. Clay–water/cement ratio hypothesis for blended cement admixed clay

Cement, ash, and soil are particulate materials, which are composed of individual units. The particulate materials can be regarded as either non-interacting or interacting materials, dependent upon the absence or presence of physicochemical interactions with the pore fluid. Ash, silt, and sand are non-interacting materials, primarily due to their low specific surface and non-electrical nature of surfaces. Cement and clay are interacting materials with water. Due to physicochemical interactions with water, the soft clay has a specific micro-fabric with a level of effective stress [21]. When the soft clay is mixed with cement, the clay and cement particles group together into large clay–cement clusters [19,20,22].

For such a system, the ash as a non-interacting material disperses the large clay–cement clusters into smaller clusters, resulting in the increase in reactive surfaces for hydration, and hence cementitious products [19,20]. Even though the ash contains a lot of silica and alumina, the pozzolanic reaction is minimal due to low $Ca(OH)_2$ (calcium ion) liberated from hydrolysis of cement. This premise is verified by the microstructural investigation (scanning electron microscope, mercury intrusion porosimetry, and thermal gravitimetry analyzer) [19,20]. The dispersing effect can be regarded akin as an addition of cement. By considering that the ash content can be equivalent to cement content [23], the equivalent cement content (C_e) is equal to ka where k is dispersing factor and a is ash content. The total cement content (C) for the blended cement admixed clay is thus the summation of input of cement (C_i) and equivalent cement content (C_e). The clay–water/cement ratio hypothesis for the blended cement admixed clay is 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". Since the pozzolanic reaction is minimal, the C_e is mainly dependent upon the dispersing effect, governing by the ash content and insignificantly alters with curing time. In other words, the k-value is practically constant with curing time for a combination of cement content and ash content.

3. Laboratory investigation

3.1. Soil sample

Soil sample is Bangkok clay collected from Ladkrabang district, Bangkok, Thailand at a 3 m depth. The soil is composed of 3% sand, 27% silt and 70% clay. Its specific gravity is 2.63. The liquid and plastic limits are in the order of 89% and 30%, respectively. Based on the Unified Soil Classification System (USCS), the clay is classified as high plasticity (CH). Groundwater was about 1.0 m from surface. Natural water content was 85%. The free swell test proposed by Prakash and Sridharan [24] shows 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 mm sieve in distilled water (V_d) to that in kerosene (V_k). This method was employed since it is a simple methodology to obtain an approximate and fairly satisfactory prediction of the dominant clay mineralogy of soil [1]. Chemical composition and grain size distribution curve of the clay are shown in Table 1 and Fig. 1, respectively. SEM photo of the natural clay is shown in Fig. 2.

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 of PC, FA and BA is also

Table 1
Chemical composition of Bangkok clay, PC, FA, and BA.

Chemical composition (%)	Bangkok clay	PC	FA	BA
SiO_2	62.83	20.90	44.72	74.12
Al_2O_3	21.34	4.76	23.69	0.57
Fe_2O_3	8.41	3.41	11.03	0.88
CaO	0.94	65.41	12.67	1.54
MgO	1.54	1.25	2.63	5.91
SO_3	1.22	2.71	1.28	3.33
Na_2O	0.28	0.24	0.07	1.71
K_2O	2.45	0.35	2.87	0.52
LOI	0.99	0.96	1.42	11.42