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Chemical stabilization of soft Bangkok clay using the blend of calcium carbide residue and biomass ash

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Abstract

The blend of calcium carbide residue (CCR) and biomass ash (BA) required as a stabilizing chemical additive which causes a pozzolanic reaction was investigated. The dissolution of CCR in water generated calcium hydroxide, $Ca(OH)_2$. This high pH solution (pH = 12.6) dissolved the amorphous Si from BA and resulted in pozzolanic products. Scanning Electron Microscope (SEM) and X-ray Diffraction (XRD) analyses indicated the existence of ettringite and non crystalline phase calcium silicate hydrate (C-S-H) after 7 days of curing. The strength development of stabilized clay with a CCR and BA blend is influenced by the interrelationship of various factors, including the binder content, the water content and curing time. From two factorial experiments, the strength of stabilized clay at specific curing time and initial water content was the function of the CCR content, the BA content and their combined effect. When the initial soil water content was constant at 1.2 and 1.4 times the optimum water content (OWC) and the binder contents ranged from 5% to 30% of the dry weight of soil, the strength depended on the clay water–binder ratio (w_c/B) and the curing time. The plot of the strength development ratio and curing time on a logarithmic scale revealed that the blend of CCR and BA rendered a different chemical reaction from cemented clay and fly ash (FA) and BA blended cement admixed clay. The strength development ratio of stabilized clay with a CCR and BA mixture exceeded those of cemented clay and FA and BA blended cement admixed clay after 28 days of curing due to the progress of the pozzolanic reaction.

Keywords: Chemical stabilization; Soft clay; Strength; Calcium carbide residue; Biomass ash; Pozzolanic reaction; Microstructure; Clay water–binder ratio

1. Introduction

Soft Bangkok clay is known as low swelling clay. The swelling potential of such clay increases with depth. It has high water content close to its liquid limit, bringing about settlement and low inherent shear strength (Horpibulsuk et al., 2007). Infrastructure development is sometimes carried out on this soft clay soil due to the difficulties of land acquisition. For road and airfield applications, Rafalko et al. (2007) studied the effectiveness of compaction using cement, quick lime and calcium carbide to increase the unconfined compressive strength of soft clay soils. Treating clay with quick lime and calcium carbide resulted in similar strength gains. They also claimed that calcium carbide could stabilize soil in the same way that hydrate lime did. Some recent research has been conducted on the applications of alternative additives for the stabilization of soft clay. Ahmed et al. (2011) recommended the

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use of furnace cement type B as a solidification material for stabilization of soft clay with recycled gypsum for embankment. O'Kelly (2011) proposed the mixture of aluminum sulfate and polyelectrolyte solutions as a chemical additive for high-plasticity organic clay.

Calcium carbide residue (CCR) or carbide lime, a byproduct of acetylene manufacturing, dissolves in water and produces $Ca(OH)_2$. An estimated volume of 21, 500 t/year in Thailand's detention pond is considered as an environmental threat (Tanalapsakul, 1998). CCR and hydrated lime are similar in their chemical and mineralogical compositions with the exception of the presence of carbon ($\approx 2\%$) in CCR (Cardoso et al., 2009). In the literatures, many kinds of biomass ash (BA), such as rice husk, wood, wheat straw and sugar cane straw, have been recognized as potential additives in portland cement due to their capacity to react with hydrated lime (Ahmaruzzaman, 2009). In cement admixed clay, it should be noted that an insufficient amount of $Ca(OH)_2$ from hydration means that fly ash (FA) and BA do not act as pozzolanic materials. As such, the role of FA and BA in soil is limited: they are dispersing agents of clay–cement clusters (Horpibulsuk et al., 2009).

Beeghly and Schrock (2009) showed the mixture of lime by products and FA to stabilize the dredge material for structural fill as a result of the pozzolanic and sulfo-pozzolanic reactions. In an earlier study by Horpibulsuk et al. (2012), the cementitious binder from the mixture of CCR and class F FA was shown to enhance the strength of silty clay in the northeast of Thailand. Among the results of preliminary studies on the stabilization of the low water content soft clay, Vichan and Rachan (2010) suggested that improvements in the unconfined compressive strengths of soft Bangkok clay due to the blend of CCR and BA highly depended on several factors: the proportion of CCR and BA, the initial soil water content, the binder content and curing time. With an initial soil moisture content at 1.2 OWC, the use of a 5% binder to stabilize soft Bangkok clay, with a blended binder proportion of CCR:BA = 60:40 rendered the highest strength after 14 days of curing.

Though some research has been done on the application of the blend of CCR and pozzolanic materials as cementitious binders, no research has been focused on the contribution of each material and their interaction in strength development. In the present paper, after discussing the microstructural examination by means of Scanning Electron Microscope (SEM) and X-ray Diffraction (XRD), the effect of each material as well as their combined effect on strength gain was determined by two factorial experiments. Further, by adopting the Clay water–Cement ratio hypothesis (Miura et al., 2001; Horpibulsuk et al., 2003, 2005) the effects of the ratio of clay water to binder content (w_c/B) on strength development at different curing times was investigated. A generalized equation is proposed for predicting the laboratory strength of stabilized clay within a certain range of water contents, binder contents and curing times. Finally, the authors compare the strength development ratio of stabilized clay with this alternative binder to other binders used in previous reports on cement admixed clay and FA, BA blended cement clay (Horpibulsuk et al., 2009, 2011a, 2011b, 2012).

2. Materials used and methodology

2.1. Materials used

2.1.1. Soil sample

Soft clay was collected from the Bangkapi district, Bangkok, Thailand at a 3–5 m. depth. The open-air dried soil was subjected to size reduction by the Los Angeles abrasion machine. Soil samples then were passed through sieve no. 4 and stored in dry containers before use. The soil water content was 8–12% by dry weight of soil. The specific gravity of the soil was approximately 2.76. The liquid and plastic limits were 81% and 35%, respectively. According to the Unified Soil Classification System (USCS), Bangkok clay was classified as a high plasticity clay, fat clay (CH). The maximum dry density (MDD) and the optimum water content (OWC) of raw clay were determined by the Standard Proctor compaction test (ASTM D698) as 14.4 kN/m^3 and 21.5%, respectively.

2.1.2. Binders

The CCR was a grayish white solid. It was generated from a Sai 5 Acetylene gas factory in Nakhon Pathom province. The BA, which was generated from the combustion process of the National power supply plant in Chachoengsao province, was composed of 42% rice husk, 24% bark, 23% eucalyptus chips and 6% board. Both the CCR and BA were ground to smaller sizes by the Los Angeles abrasion machine and passed through sieve no. 325. The specific gravity of CCR and BA were 2.25 and 1.95, respectively. The pH at 20 °C of CCR and BA measured by a lab 850 set Schott pH meter were 12.6 and 9.3, respectively (solid: liquid ratio = 1:2). The chemical compositions of the binders were determined by X-ray fluorescence (XRF), and the results are shown in Table 1.

Table 1
Chemical compositions of binders.

(%) Chemical compositions	BA	CCR
SiO_2	74.12	5.71
Al_2O_3	0.57	2.61
Fe_2O_3	0.88	0.72
CaO	5.91	83.1
MgO	1.54	0.80
SO_3	0.5	0.90
Na_2O	3.33	0.05
K_2O	1.71	0.08
Others	3.90	0.29
LOI	7.45	5.71