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Stabilization of Soft Clay Using Waste-Based Cement

Supakij Nontananandh[1]* and Naphol Yoobanpot [1,2]

ABSTRACT

This research focused on the potential utilization of waste-based cement (WBC) as a stabilizer to improve the compressive strength of soft clay and also aimed to verify the hardening effects of WBC compared to ordinary Portland cement (OPC). Evaluation of hardening effects was performed based on the compressive strength test and by means of physicochemical tests. The experimental results revealed that the unconfined compressive strengths of soil mixes can be improved by stabilizing with WBC to a similar extent to that achieved using OPC. The improvement in strength was due to the enhancement of hydration producing calcium silicate hydrate and calcium aluminate hydrate.

Keywords: soil stabilization, waste utilization, compressive strength, cement, waste based cement

INTRODUCTION

Many researchers have proposed alternative approaches to solve environmental problems due to the progressive rate of waste generation. Some acceptable waste disposal projects are outweighed by the disadvantages of the rising price of land, high operation costs and more stringent regulations. Therefore, recent studies have focused on the utilization of wastes as raw materials for construction and cement manufacturing according to 3R (Reduce, Recycle, Reuse) waste management (Cyr *et al.*, 2007; Thongdaeng *et al.*, 2010; Nontananandh *et al.* (2011a).

The potential of burning various industrial wastes with appropriate mixed proportions to produce cementing materials comparable to ordinary Portland cement (OPC) has been investigated by many researchers in recent years (Shiha *et al.*, 2003; Bernado *et al.*, 2007; Puertas *et al.*, 2008). In Thailand, there are currently not many research studies on the production of waste-based clinker. Pimraksa *et al.* (2009) studied the production of Belite cement using industrial by-products as raw materials with a burning temperature of 1,200 °C.

Previous studies by Yoobanpot *et al.* (2010) and Nontananandh *et al.* (2011b) reported on attempts to produce clinker and cementing material using the combination of certain types of industrial wastes. The waste-based cement contained the essential Bougue's compounds such as C_3S, C_2S, C_3A and C_4AF and had a hardening effect similar to that of OPC. The results of analysis also revealed that the cement produced from wastes was an environmentally friendly product having a heavy metals content that conformed to the US Environmental Protection Authority's standard (USEPA, 1993; Nontananandh, 2011b). However, the quality of the so-called waste-based cement, such as its hydraulic properties and enhancement on hydration, still need to be improved. Its potential utilization as a construction material in

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place of OPC also needs to be established.

The main objective of this study was to investigate the strength development of stabilized soil using waste-based cement (WBC) as a stabilizer. Evaluation of hardening effects was performed based on the compressive strength test and by means of physicochemical tests such as X-ray diffraction (XRD), scanning electron microscopy (SEM) and suction tests.

MATERIALS AND METHODS

Materials

Soft clayey soil used in this study, generally known as soft Bangkok clay, was sampled between a depth of 3–8 m at the site of a diversion canal close to the Second Bangkok International Airport (Suvarnabhumi Airport), Samut Prakan province, Thailand.

Upon visual inspection, the soil had a dark gray color with a light organic smell. The soil was very soft and contained a high water content with an average natural water content (w_n) of 101.43%, close to the liquid state (w_{LL} = 99.86%). Other physical properties were a plastic limit (w_{PL}) of 39.71%, a plasticity index of 60.71%, a bulk density of 1.51 t.m^{-3} and a specific gravity of 2.69. According to the unified soil classification system (American Society for Testing and Materials, 1985), the soil was classified as clay with high plasticity (CH). Subsequently, the unconfined compressive strength (UCS) of an undisturbed sample was very low (average q_u = 0.10 ksc) while the sensitivity was rather high (average 6.83).

A typical XRD pattern of the soil is shown in Figure 1 and indicates that the soil was composed of large amounts of silica (in the form of quartz) as a primary mineral and some clay minerals such as kaolinite, illite and montmorillonite.

Specimen preparation and tests

The waste-based cement (WBC) obtained from the combination of industrial wastes—namely, ark shell, limestone powder, and water supply sludge with hydrated lime—was the highlight stabilizer used in this study. The processes of clinkerization and cement blending as described by Nontananandh (2011b) were adopted.

Mixing and preparation of specimens were performed in accordance with the method of making and curing noncompacted stabilized soil specimens based on the Japanese Geotechnical Society (1990). The initial mixing water content was specified at its natural water content. The stabilizer content was 200 kg.m^{-3} as recommended (Department of Highway (DOH), Thailand and Japan International Cooperation Agency (JICA), 1998).

The soil was mixed with WBC and OPC Type I as a standard control test, and then cylindrical specimens of 5 cm in diameter by 10 cm long were made. After molding, specimens were sealed tightly in plastic sheets to prevent moisture loss due to surface evaporation. The unconfined compression test was performed at curing times of 3, 7 and 28 d for both mixtures.

Investigations on the clay minerals of untreated soil, C_3S and C_2S compounds of anhydrous WBC and OPC and reaction products were performed by XRD analysis. The XRD tests were performed using a Philips X'Pert

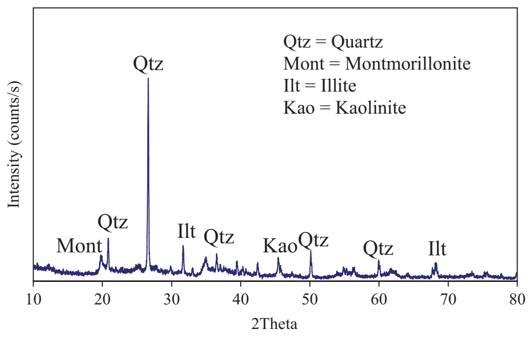


Figure 1 X-ray diffraction patterns of untreated soil.

Diffractometer with an input energy of 40 kV and 30 mA and a scanning speed of 2 degrees.min^{-1}. SEM was used to investigate the reaction products and to observe changes in the microstructures of the stabilized soil. Observations were performed on the same specimens after strength tests, using a scanning electron microscope (model JEOL JSM 6510, Japan) with a probe current of 5–10 mA and an accelerating voltage of 10 kV.

Another set of specimens was prepared for measuring the change in relative humidity and matric and total suction of the stabilized soil against time (after curing for 3, 7 and 28 d). Figure 2 illustrates the experimental setup for total suction measurement of specimens carefully wrapped and contained in a closed system with controlled temperature at 20 ± 2 °C. The output signal was measured consecutively with time until the signal became steady and stable.

RESULTS AND DISCUSSION

Strength characteristics and change in moisture content

The strength development characteristics of the stabilized soil are shown in Figure 3. The experimental results revealed that the unconfined compressive strength increased with the curing time for both mixtures. The strengths of soil mixed with the WBC were identical to that of OPC at a short curing time and became slightly higher after 28 d.

Consequently, a reduction in the water content and the subsequent decreasing rate were of special interest since, it was believed that both were involved in the formation of hydration products and strength development. The change in the moisture content with curing time is illustrated in Figure 4. For both the WBC and OPC soil mixtures, the moisture content decreased markedly after mixing for 3 d and then proceeded slowly to be almost constant after 28 d. However, the reduction in the water content and the decreasing rate of the WBC-stabilized soil seemed to be slightly higher than for the OPC-stabilized soil.

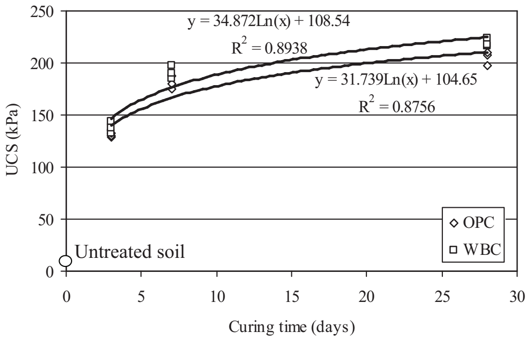


Figure 3 Unconfined compressive strength (UCS) against curing time for waste-based cement (WBC) and ordinary Portland cement (OPC).

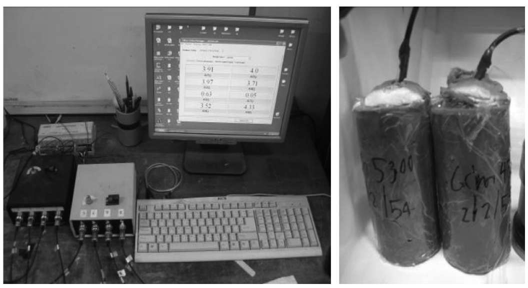


Figure 2 Suction test equipment consisting of datalogger unit (left) and relative humidity sensors attached to carefully wrapped specimens (right)

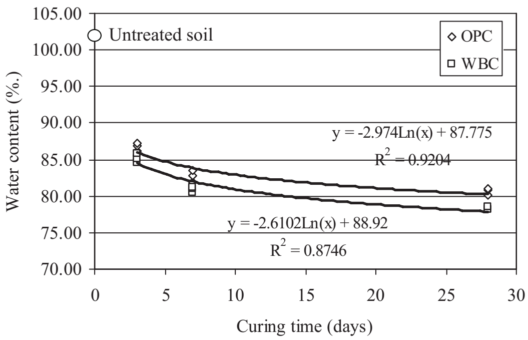


Figure 4 Water content against curing time for waste-based cement (WBC) and ordinary Portland cement (OPC).

Therefore, it was assumed that the strength development of the soil cement was affected by the changes in the solid phases during hydration.

Change in mineral composition and microstructure in relation to strength development

Typical X-ray diffractographs for both the WBC and OPC mixtures revealed that the calcium silicate hydrate (CSH), calcium hydroxide (CH) and calcium aluminate hydrate (CAH) could be well identified from the initial stage of reaction. The focused peaks of CSH increased gradually, while those of the major cementitious compounds such as C_3S and C_2S decreased with curing time, as shown in Figures 5 and 6. The intensities of these compounds at the specified curing times were detected and are summarized in Table 1. Figure 7 shows the relationship between the UCS and the CSH intensity. It is found that the CSH intensity of OPC- and WBC-stabilized soil increased with curing time. The results obtained in this study agreed well with those reported by Murat (1983). However, the CAH intensity of the OPC–stabilized soil tended to be constant, while that of WBC tended to increase with curing time as shown in Figure 8.

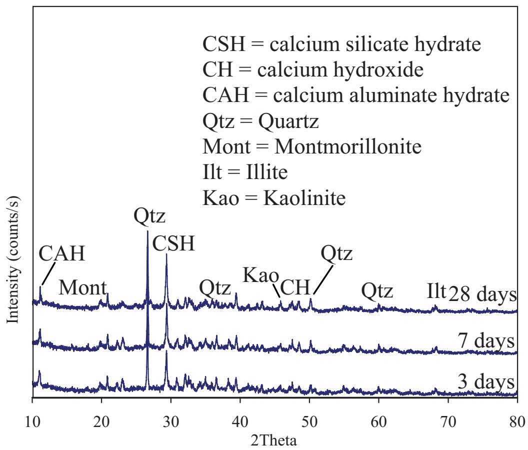


Figure 5 X-ray diffraction patterns against curing time of soil stabilized with waste-based cement (WBC).

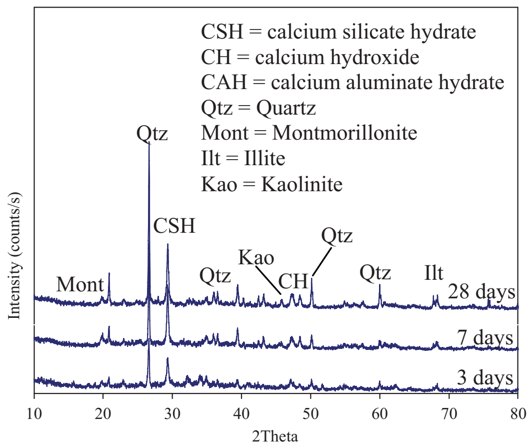


Figure 6 X-ray diffraction patterns against curing time of soil stabilized with ordinary Portland cement (OPC).

Table 1 Cement compounds and hydration products content for ordinary Portland cement (OPC) and waste-based cement (WBC).

Compound	OPC Curing time (d)			WBC Curing time (d)		
	3	7	28	3	7	28
C_3S	91	80	72	139	135	126
C_2S	74	70	66	102	99	91
CSH	259	444	486	318	359	363
CH	57	81	101	65	78	98
CAH	88	84	86	171	198	205

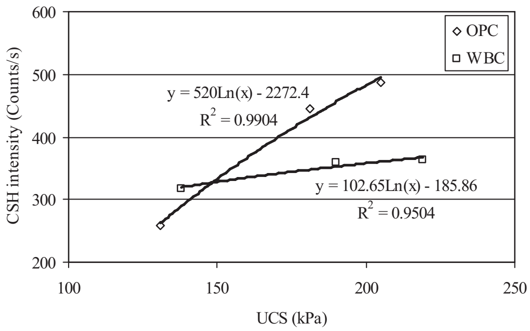


Figure 7 Unconfined compressive strengths (UCS) against calcium silicate hydrate (CSH) intensity for waste-based cement (WBC) and ordinary Portland cement (OPC).

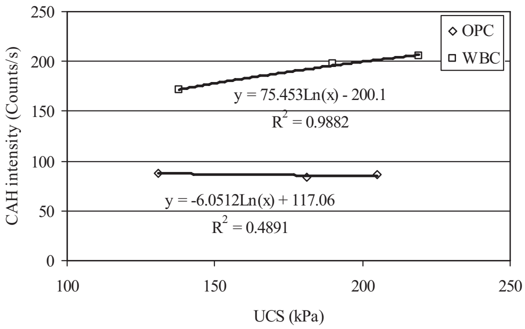


Figure 8 Unconfined compressive strengths (UCS) against calcium aluminate hydrate (CAH) intensity for waste-based cement (WBC) and ordinary Portland cement (OPC).

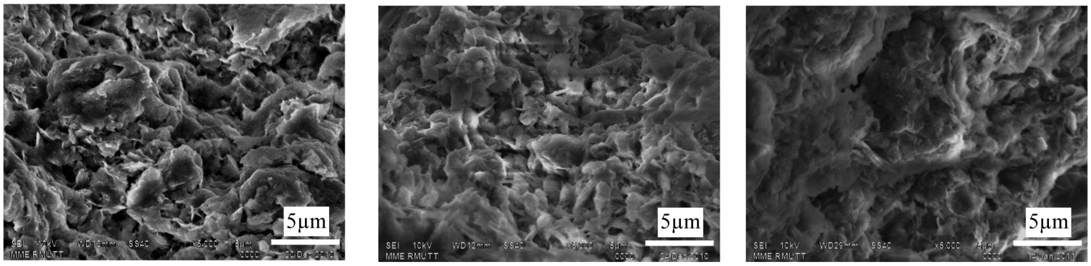
The formation of CSH products and the rate of reaction for C_3S and C_2S seemed to be more pronounced in the OPC-stabilized soil, which therefore contributed to strength development in the soil cement. However, a higher reflection of CAH was obtained from the WBC-stabilized soil. This indicated that the strength development of soil when mixed with WBC was attributed to the formation of CSH and CAH, which resulted in a substantial decrease in the moisture content.

The electron micrographs of the soil stabilized with WBC and OPC, observed at 3, 7 and 28 d are illustrated in Figure 9. It can be seen that the overall microstructures of both mixtures were identical. Reaction products such as CSH were abundantly produced, resulting in cementing soil particles on the surfaces. For the WBC-stabilized soil, CAH can also be clearly observed in Figure 9(b). However, no marked changes in the overall microstructures could be observed in the long term. The results from both the XRD analysis and SEM micrographs conformed well with those obtained from the strength tests. In addition, the results were similar to those found by Horpibulsuk *et al*. (2010).

Changes in the relative humidity and total suction of the stabilized soils are illustrated in Figures 10–13. Table 2 summarizes the values obtained from those characteristic graphs where the signal outputs became stable. The relative humidity of the WBC-stabilized soil substantially decreased while the total suction markedly increased with curing time. For the OPC-stabilized soil, no marked changes in the relative humidity were observed. It was found that the total suction of the WBC-stabilized soil was higher than that of the OPC-stabilized soil over all the curing times. This could be reflected by a substantial decrease in the moisture content when WBC was used as a stabilizer, resulting in a slight increase in the micro pore spaces in the stabilized soil, as can be observed in Figure 9(b). Extracting moisture that existed in the pore spaces by using reaction products led to an increase in the dry density and thus provided a reduced water-to-stabilizer ratio that aided further hardening.

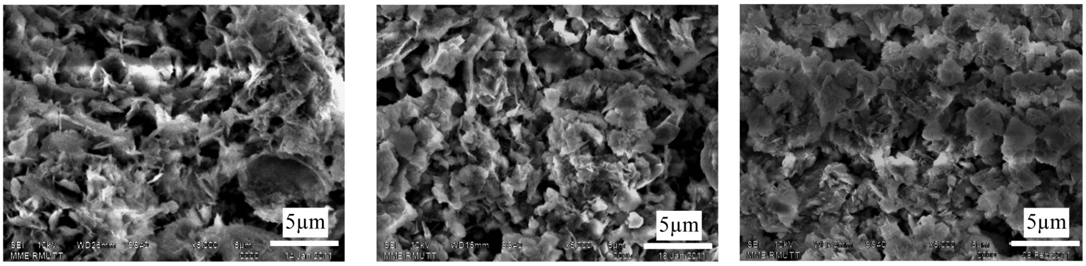
CONCLUSION

The potential utilization of various types of industrial wastes as raw materials to produce waste-based cement was studied based on the newly developed concepts and techniques. As a stabilizer for soft clayey soil, the waste-based



3 days 7 days 28 days

(a) Soil stabilized with OPC



3 days 7 days 28 days

(b) Soil stabilized with WBC

Figure 9 Scanning electron microscope images of soil stabilized with ordinary Portland cement (OPC) and soil stabilized with waste-based cement (WPC).

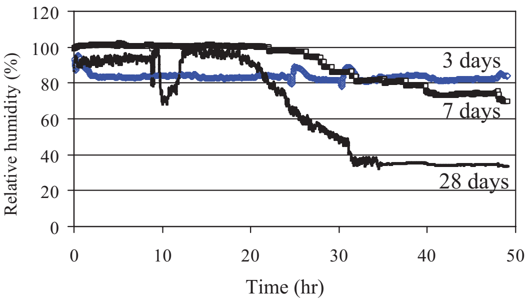


Figure 10 Change in relative humidity over time of soil stabilized with waste-based cement.

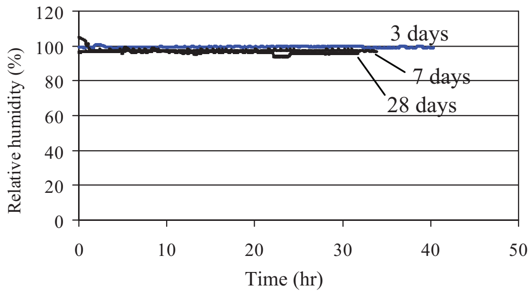


Figure 11 Change in relative humidity over time of soil stabilized with ordinary Portland cement.

cement had hydraulic properties to improve the strength of soft clay comparable to ordinary Portland cement. The newly developed cement provided hydration and subsequent reaction products such as calcium silicate hydrate and calcium aluminate hydrate, which contributed to the strength development of the stabilized soil.

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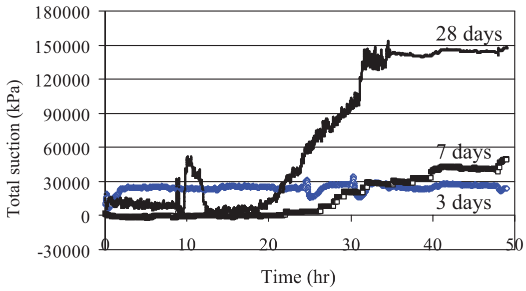

Figure 12 Total suction development over time of soil stabilized with waste-based cement .

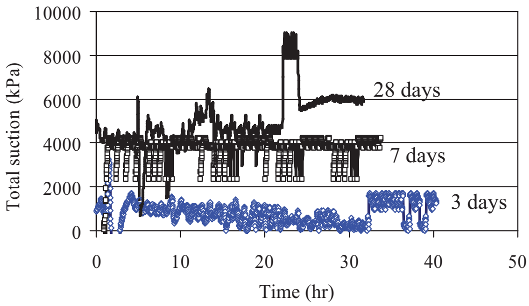

Figure 13 Total suction development against time of soil stabilized with ordinary Portland cement.

Table 2 Relative humidity and total suction of soil stabilized with ordinary Portland cement (OPC) and soil stabilized with waste-based cement (WPC).

Soil sample	Relative humidity (%)	Total suction (kPa)
Untreated	-	2.03*
OPC		
3 days	98.8–99.1	1,200–1,600
7 days	96.9–97.1	3,900–4,200
28 days	95.6–95.7	5,900–6,200
WBC		
3 days	83.7–84.1	23,000–24,000
7 days	69.4–69.7	49,000–50,000
28 days	33.5–33.6	147,000–148,000

* = By metric suction.

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