

Effect of Cement Replacement by Rice Husk Ash on Soft Soil Stabilization

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ABSTRACT

The characteristics of soft soil improvement using cement and rice husk ash were studied. Compressive strength testing of stabilized soil was investigated with various curing times of 3, 7, 14 and 28 d. The correlation between strength development and reaction products was investigated using X-ray diffraction analysis after the strength tests and changes in the stabilized soil structure were investigated using scanning electron microscopy. The results revealed that the soil strength increased when the soil was stabilized with cement and partial replacement of cement with rice husk ash. The results indicated that 30% rice husk ash was the appropriate content for partial cement replacement to produce a stabilized soil strength of 424, 722, 915 and 1,126 kPa at 3, 7, 14 and 28 d curing, respectively. It was also found that the increase in the strength of the stabilized soil was relative to the formation of major reaction products such as calcium silicate hydrate.

Keywords: soil improvement, cement, rice husk ash, hydration products, compressive strength

INTRODUCTION

Soil stabilization is one technique widely used to improve the undesirable properties of soft soil such as low shear strength, low bearing capacity and high settlement, which are problematic in geotechnical engineering (Bell, 1993; Chew *et al.*, 2004; Mohammad and Alipour, 2012). The stabilization process involves combining the appropriate proportion of soft soil and stabilizer to increase the shear strength and bearing capacity of the soil with a subsequent decrease in soil settlement. The traditional basic stabilizers are cementitious materials such as ordinary Portland cement (OPC) and hydrated lime. In addition, soil improvement studies have proposed a combination of the stabilizing technique with pozzolanic materials such as industrial waste (Kamon and

Nontananandh, 1991; Koliass *et al.*, 2005; Manso *et al.*, 2013) and natural agricultural wastes (Ali Jawaid and Shukla 1996; Sivapulliah *et al.*, 2004; Garcia and Sousa-Coutinho, 2013).

Rice husk ash (RHA) is a natural agricultural waste from rice mill factories and contains pozzolanic material. Rice mill factories create a waste product called raw husk which is used as heating fuel in rice mill processing and produces the RHA as a byproduct from the burnt raw husk. Office of Agricultural Economics of Thailand (2013) reported an annual rice production of approximately 30 million t of which more than 20% becomes raw husk. As this husk is fired, approximately 25% RHA is generated, though the amount of RHA varies considerably according to the heating process, burning temperature and rice type (Koteswara *et al.*, 2011).

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There are several advantages in using the RHA in cement replacement for concrete applications. Mehta (1992) studied the engineering benefits of RHA replacement in cement to enhance the concrete durability compared with cement alone. The pozzolanic properties of the RHA that are beneficial in concrete are increased compressive strength due to the pozzolanic reaction, improved workability, relieve of creep and shrinkage problems, reduced segregation and bleeding, reduced concrete temperature due to the low heat of hydration and prevention of steel corrosion in concrete due to the low permeability properties from chloride diffusion attack (Saraswathy and Song, 2007; Ganesan *et al.*, 2008; Dabai *et al.*, 2009; Marthong, 2012). The use of the RHA not only takes advantage of reductions in the amount of OPC used which consequently lowers material costs but also mitigates environmental problems such as dusting and leaching from the landfill area (Shazim *et al.*, 2011; Nagrale *et al.*, 2012; Opeyemi and Makinde, 2012).

The application of RHA to relieve geotechnical problems has been proposed by some researchers. Basha *et al.* (2005) found that the combination of 6–8% cement and 10–15% RHA could improve soil properties, decrease plasticity and increase the soil strength. Brooks (2009) suggested the combination of 12% RHA and 25% fly ash as suitable for strengthening the expansive soil sub-grade and reducing soil swell behavior. Koteswara *et al.* (2011) noticed that the compressive strength at 28 d of expansive soil was increased approximately five times by the addition of 20% RHA with 5% lime and 3% gypsum. However, those studies suggested considering the appropriate proportion of the RHA prior to seeking approval due to the uncertainty of RHA properties in different areas.

The main objective of the current study was to determine the strength of stabilized, soft, clayey soil using OPC and partially replacement of OPC with RHA. Based on compressive strength testing, strength development was evaluated

in order to compare the reaction products from the hydration process that were examined by X-ray diffraction (XRD) analysis. Observation of changes to the stabilized soil structure were performed using scanning electron microscopy (SEM).

MATERIALS AND METHODS

Materials

Natural, soft, soil samples were collected from construction sites of the flood barrier protection project on the banks of the Chaophraya River, Laemfapha, Phrasamut Chedi, Samutprakan, Thailand. The soil was sampled at a depth of 3–7 m using a backhoe. According to the unified soil classification system (American Society for Testing and Materials, 1985), the soil can be classified as clay with high plasticity and further physical and engineering properties as shown in Table 1.

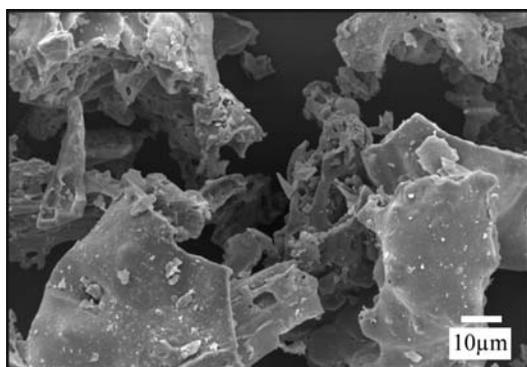
The RHA used in this study was sampled from a rice mill factory in Chainat, Thailand. The chemical composition of the RHA mainly consisted of silicon oxide (SiO_2) and minor oxides as shown in Table 2. The specific gravity of the RHA was 2.10 and fineness was in the range 2,900–3,200 $\text{cm}^2 \cdot \text{g}^{-1}$ after grinding for 60 min. The surface texture of the RHA particles was rough surfaced and the particles were nonuniformly shaped (Figure 1).

Table 1 Physical and engineering properties of natural soil.

Property (unit)	Value
Natural water content (%)	86.37
Liquid limit (%)	83.72
Plastic limit (%)	35.05
Plasticity index (%)	48.67
Wet unit weight ($\text{kg} \cdot \text{m}^{-3}$)	1,460
Specific gravity	2.66
Untreated soil strength (kPa)	5–12
Color	Dark gray

Table 2 Chemical compositions of rice husk ash.

Compound	% by dry weight
SiO ₂	91.94
Al ₂ O ₃	0.51
Fe ₂ O ₃	0.37
CaO	1.48
MgO	0.46
SO ₃	0.13
K ₂ O	1.92
Other (P ₂ O ₅ , Na ₂ O, etc.)	1.17
Loss on ignition	2.02

**Figure 1** Scanning electron micrograph of rice husk ash after grinding for 60 min.**Specimen preparation and tests**

The stabilizer used in this study was OPC only and partial replacement of OPC with the RHA. DOH and JICA (1998) suggested a reasonable OPC content for improvement of soft Bangkok clay was within the range 80–200 kgm⁻³ of soil and a W/B ratio (the ratio of the weight of water to the weight of OPC) of about 0.8–1.2. To conform to these suggested specifications and those of Nonthananandh *et al.* (2004), an OPC content of 200 kg.m⁻³ of soil and a W/B ratio of 0.8 were adopted. In this study, SCM00 represented the stabilized soil with OPC only (control) while SCM10, SCM20, SCM30 and SCM40 represented stabilized soil mixed with OPC and with partial replacement of the OPC with RHA at 10, 20, 30 and 40% by dry weight, respectively.

Specimens were prepared in accordance with the JGS T821–1990 standard (Japanese Geotechnical Society, 1990) using the noncompacted-stabilized soil method. The cylindrical specimens (5 cm in diameter, 10 cm long) were prepared for unconfined compressive strength (UCS) testing. After molding for 24 hr, specimens were removed and then covered with a thin plastic sheet to prevent moisture loss. The UCS test was performed after 3, 7, 14 and 28 d curing.

Reaction products were investigated using X-ray diffraction (XRD) following the failure of specimens after UCS testing to evaluate the correlation between the UCS and the reaction product. Observations were undertaken using a scanning electron microscope (SEM) after gold plating of samples from the same failure specimens which had been used to observe changes in the microstructure of the stabilized soil.

RESULTS AND DISCUSSION**Strength characteristics of stabilized soil with relations to RHA substitution content**

The average UCS strength for three samples of treated soil for different curing times is shown in Table 3 and Figure 2 indicating that the UCS strength for all mixtures increased with curing time. At 3 d, the control strength of SCM00 (only OPC content) produced the greatest soil strength and this decreased with an increase in the RHA substitution content. At 28 d, some mixtures with an RHA content (SCM10 to SCM30) had a higher strength than SCM00, with SCM30 producing the highest compressive strength whereas the SCM40 sample had the lowest. The proposed equations for strength prediction with curing time had high coefficients of determination and are presented in Table 4.

Changes in the water content of stabilized soil are shown in Table 5. The water content of all mixtures decreased with curing time. In addition,

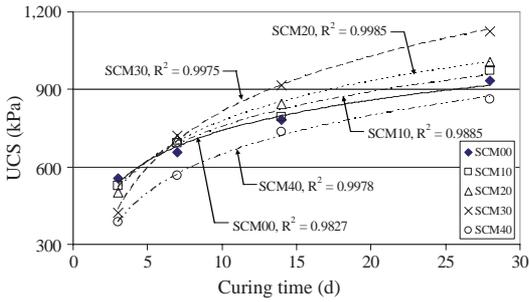


Figure 2 Unconfined compressive strength (UCS) versus curing time for different stabilized soil samples, where SCM00 = stabilized soil with ordinary Portland cement (OPC) only (control), SCM10, SCM20, SCM30 and SCM40 = stabilized soil mixed with OPC and with partial replacement of the OPC with rice husk ash at 10, 20, 30 and 40% by dry weight, respectively, and R^2 is the coefficient of determination.

the observed water content decreased with an increase in the RHA substitution content. It is assumed that the reduction in the water content was effected by the hydration process and its impact on soil strength development. The modulus of elasticity (E_{50}) is the essential parameter in the soil settlement calculation as shown in Table 6. The results showed that E_{50} for all stabilized soil samples increased with curing time and SCM00 had the highest modulus of all the mixtures at 3 d curing. At 28 d, the mixtures SCM10–SCM30 had a E_{50} value greater than SCM00 while SCM40 exhibited the lowest. This result was similar to the strength characteristic development and relationship between UCS and E_{50} as shown in Figure 3.

The strength development in relation to RHA replacement is shown in Figure 4. At 3 d, the stabilized soil strength decreased with increased RHA substitution content. However at 7, 14 and

Table 3 Unconfined compressive strength (UCS) of soil samples after different days curing time for all mixtures.

Sample	UCS (kPa) after curing for			
	3 d	7 d	14 d	28 d
SCM00	554	658	783	935
SCM10	526	693	792	973
SCM20	502	708	845	1,007
SCM30	424	722	915	1,126
SCM40	385	567	735	863

SCM00 = stabilized soil with ordinary Portland cement (OPC) only (control), SCM10, SCM20, SCM30 and SCM40 = stabilized soil mixed with OPC and with partial replacement of the OPC with rice husk ash at 10, 20, 30 and 40% by dry weight, respectively.

Table 4 Proposed equations for strength prediction with days curing time for different soil stabilized samples.

Sample	Equation	R^2
SCM00	$SS = 170.39 \ln(CT) + 348.45$	0.9827
SCM10	$SS = 194.47 \ln(CT) + 307.67$	0.9885
SCM20	$SS = 223.73 \ln(CT) + 261.23$	0.9985
SCM30	$SS = 311.69 \ln(CT) + 94.21$	0.9975
SCM40	$SS = 216.79 \ln(CT) + 148.87$	0.9978

SS = Stabilized soil strength (kPa), CT = Curing time (d), Ln = Natural logarithm.

SCM00 = stabilized soil with ordinary Portland cement (OPC) only (control), SCM10, SCM20, SCM30 and SCM40 = stabilized soil mixed with OPC and with partial replacement of the OPC with rice husk ash at 10, 20, 30 and 40% by dry weight, respectively; R^2 = Coefficient of determination.

28 d, the soil strength with an RHA substitution content of 10%, 20% and 30% was higher than for SCM00 with only OPC content. In addition, SCM40, which contained 40% RHA replacement, produced the lowest strength of all mixtures with curing time. There was a similar trend in the relationship between E_{50} and the RHA replacement content as shown in Figure 5. Based on the strength characteristic results and economics, using 30% RHA for partial replacement of OPC is suggested as the optimum content for soil stabilizer.

Microscopic investigation on reaction products in relation to strength development

The stabilized soil sample SCM30, which had the optimum determined content of RHA replacement, was selected for further micro analysis of the reaction products compared with SCM00. The XRD analysis pattern of the stabilized soil is shown in Figure 6 for SCM00 and in Figure 7 for SCM30. Figure 6 identifies that the stabilized soil SCM00 consisted of the reaction products calcium silicate hydrate (CSH), calcium hydroxide (CH), tri-calcium silicate

hydrate (C_3S), di-calcium silicate hydrate (C_2S) together with a silica form as quartz (Qzt) and clay minerals content such as montmorillonite (Mont), illite (Ilt) and kaolinite (Kao). It was found that the formation of the main products of the hydration reaction process (CSH and CH) increased with an increase in curing time while the formation of C_3S and C_2S gradually decreased with time. A similar result was observed with SCM30 as shown

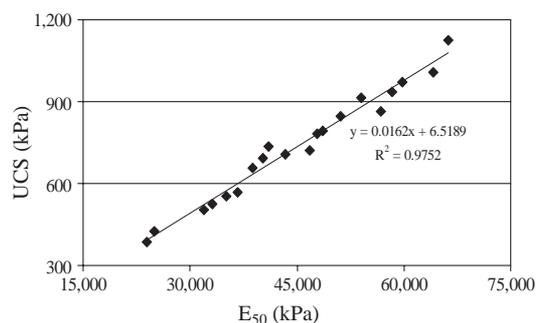


Figure 3 Relationships between unconfined compressive strength (UCS) and modulus of elasticity (E_{50}) for all mixtures, where R^2 is the coefficient of determination.

Table 5 Water content of stabilized soil with different days curing time.

Sample	Water content (%) after curing for			
	3 d	7 d	14 d	28 d
SCM00	83.59	80.36	76.64	71.25
SCM10	82.62	79.36	75.22	69.11
SCM20	79.85	78.25	74.13	67.78
SCM30	76.22	74.27	71.56	65.25
SCM40	74.34	71.63	69.07	64.08

SCM00 = stabilized soil with ordinary Portland cement (OPC) only (control), SCM10, SCM20, SCM30 and SCM40 = stabilized soil mixed with OPC and with partial replacement of the OPC with rice husk ash at 10, 20, 30 and 40% by dry weight, respectively.

Table 6 Modulus of elasticity (E_{50}) with different days curing time.

Sample	E_{50} (kPa) after curing for			
	3 d	7 d	14 d	28 d
SCM00	35,067	38,706	47,863	58,364
SCM10	33,145	40,256	48,567	59,738
SCM20	31,988	43,352	51,124	64,117
SCM30	24,941	46,728	53,944	66,249
SCM40	23,887	36,645	41,053	56,795

SCM00 = stabilized soil with ordinary Portland cement (OPC) only (control), SCM10, SCM20, SCM30 and SCM40 = stabilized soil mixed with OPC and with partial replacement of the OPC with rice husk ash at 10, 20, 30 and 40% by dry weight, respectively.

in Figure 7. The XRD pattern of SCM30 revealed the main products formed were CSH, CH, C₃S and C₂S together with similar clay mineral content as the other samples.

The compound intensities of the products detected over different curing times are shown in Table 7 for SCM00 and Table 8 for SCM30 with

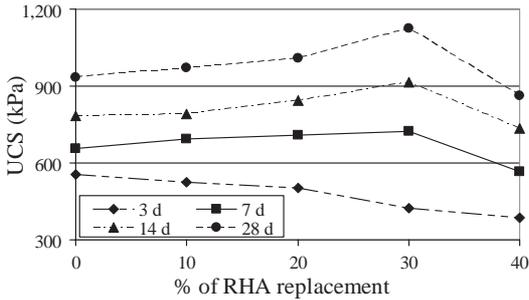


Figure 4 Unconfined compressive strength (UCS) versus percentage rice husk ash (RHA) replacement with different days curing time.

SCM00 having a higher CSH intensity than SCM30 at 3 d and then it was lower at 28 d curing. The X-ray micrographs of CSH showed its formation had a similar trend to the strength characteristic curves, which suggested that the product formation had an effect on strength development. The content of cementitious compounds such as C₃S and C₂S

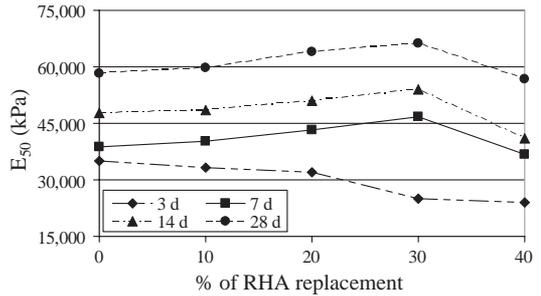


Figure 5 Modulus of elasticity (E₅₀) versus percentage rice husk ash (RHA) replacement with different days curing time.

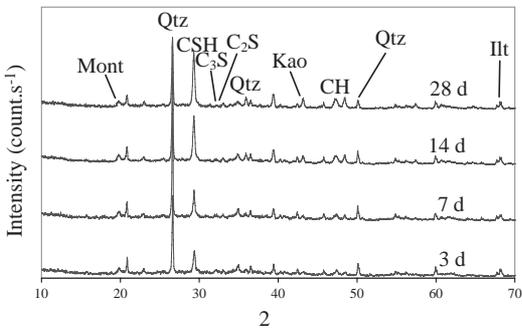


Figure 6 X-ray diffraction patterns for different days curing time of stabilized soil with only ordinary Portland cement added (control), where CSH = Calcium silicate hydrate, CH = Calcium hydroxide, C₃S = Tri-calcium silicate hydrate, C₂S = Di-calcium silicate hydrate, Qtz = Quartz, Mont = Montmorilonite, Illt = Illite, Kao = Kaolinite.

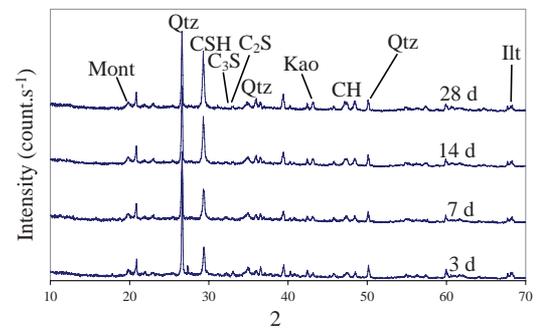


Figure 7 X-ray diffraction patterns versus different days curing time of stabilized soil mixed with ordinary Portland cement (OPC) and with partial replacement of the OPC with RHA at 30% by dry weight, where CSH = Calcium silicate hydrate, CH = Calcium hydroxide, C₃S = Tri-calcium silicate hydrate, C₂S = Di-calcium silicate hydrate, Qtz = Quartz, Mont = Montmorilonite, Illt = Illite, Kao = Kaolinite.

decreased with time due to the hydration process and thus created increased amounts of products such as CSH and CH with time. In addition, the pozzolanic reaction from the RHA produced a higher CSH intensity which resulted in a relatively higher soil strength. The relationship between strength and CSH intensity is presented in Figure 8.

Changes in the stabilized soil structure due to the cement hydration process could be observed using the SEM technique after UCS testing. Observation of SCM00 (Figure 9) indicated that there was large amount of CSH cementitious product formed which covered the soil surface from 3 to 7 d. At 14 d, these reaction products had hardened on the soil surface. At 28 d, intercrossing of the CSH, rod-like formations made the overall stabilized soil structure denser and stiffer. Figure 10 shows the SEM micrographs of SCM30 which resemble those observed for

SCM00, indicating that CSH was formed in the early stage and its relative growth had developed into the rod-like formations at 28 d. It can be concluded that the formation and growth of major reaction products affected the stabilized soil structure which became denser and stronger

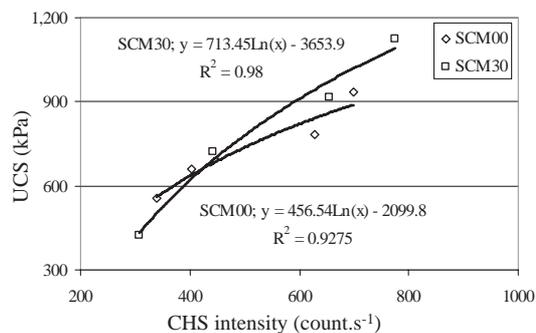


Figure 8 Unconfined compressive strength (UCS) versus calcium silicate hydrate (CSH) intensity, where R^2 is the coefficient of determination.

Table 7 Hydration products and cement compounds for stabilized soil with the control of only ordinary Portland cement added (SCM00) with different days curing time.

Compound	SCM00 after curing for			
	3 d	7 d	14 d	28 d
CSH (cps)	339	403	628	698
CH (cps)	74	92	127	132
C ₃ S (cps)	93	72	69	50
C ₂ S (cps)	80	74	71	51

cps = Count.s⁻¹ and refers to peak intensity detected at a specific angle of 2θ.

CSH = Calcium silicate hydrate, CH = Calcium hydroxide, C₃S= Tri-calcium silicate hydrate, C₂S= Di-calcium silicate hydrate, Qtz = Quartz, Mont = Montmorillonite, Illt = Illite, Kao = Kaolinite

Table 8 Hydration products and cement compounds for stabilized soil mixed with ordinary Portland cement (OPC) and with partial replacement of the OPC with rice husk ash at 30% by dry weight (SCM30) with different days curing time.

Compound	SCM30 after curing for			
	3 d	7 d	14 d	28 d
CSH (cps)	307	442	654	774
CH (cps)	65	81	117	158
C ₃ S (cps)	81	65	63	56
C ₂ S (cps)	76	69	66	53

cps = Count.s⁻¹ and refers to peak intensity detected at a specific angle of 2θ.

CSH = Calcium silicate hydrate, CH = Calcium hydroxide, C₃S= Tri-calcium silicate hydrate, C₂S= Di-calcium silicate hydrate, Qtz = Quartz, Mont = Montmorillonite, Illt = Illite, Kao = Kaolinite

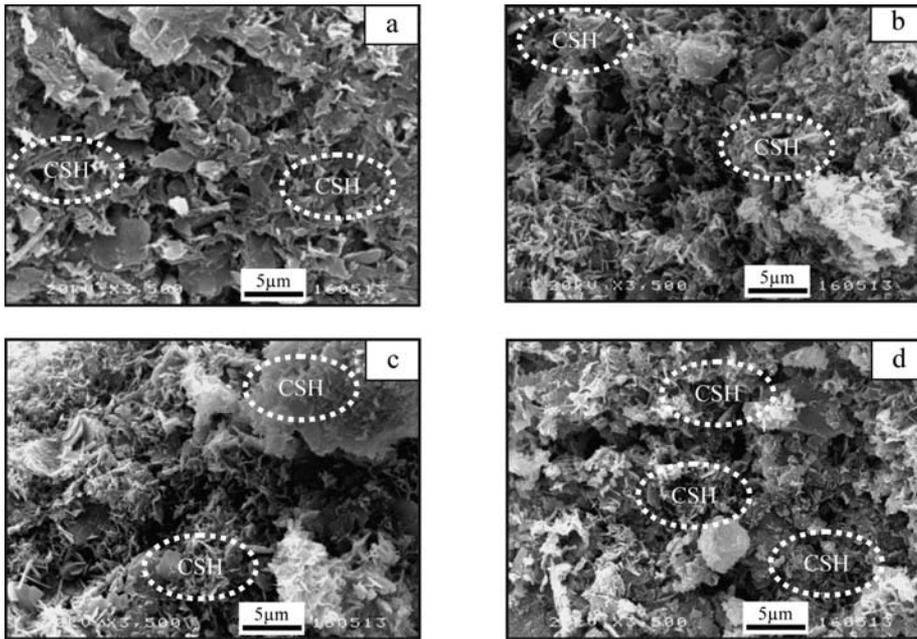


Figure 9 Scanning electron micrographs of stabilized soil with ordinary Portland cement (OPC) only (control) showing the development of calcium silicate hydrate (CSH) after different days curing time of (a) 3 d, (b) 7 d, (c) 14 d and (d) 28 d.

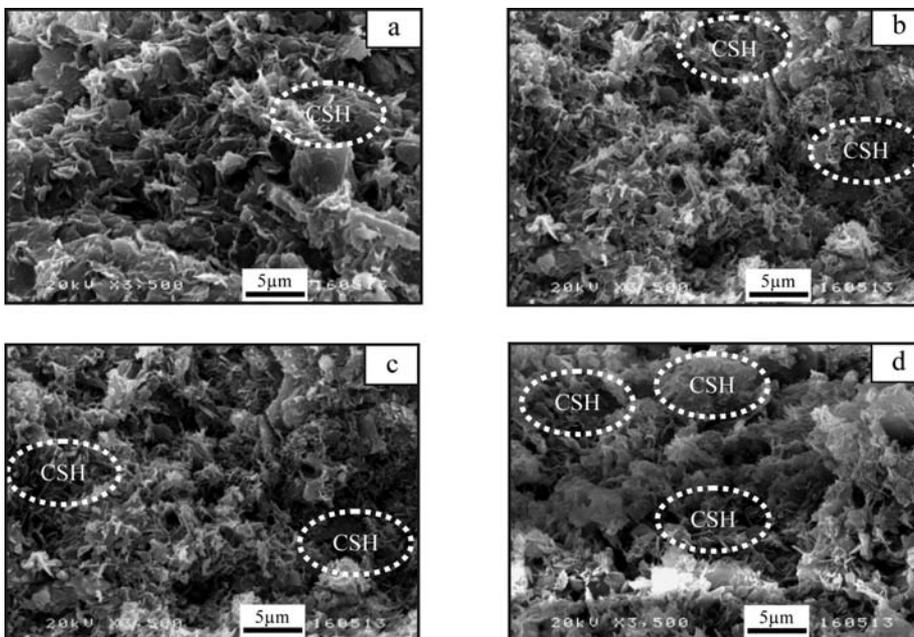


Figure 10 Scanning electron micrographs of stabilized soil mixed with ordinary Portland cement (OPC) and with partial replacement of the OPC with rice husk ash at 30% by dry weight showing the development of calcium silicate hydrate (CSH) after different days curing time of (a) 3 d, (b) 7 d, (c) 14 d and (d) 28 d.

resulting in progressive strength development. The study results from the compressive strength tests, XRD analysis and SEM observations agreed with the reports of Horpibulsuk *et al.* (2009) and Nontananandh and Yoobanpot (2012).

CONCLUSION

Based on the results of the present investigation, the compressive strength of soil was improved when stabilized with cement and with cement partially substituted with RHA. The potential use of an RHA substitution content of 30% as a cement replacement material to obtain higher strength was suggested. At 28 d curing, the stabilized soil strength with 30% RHA replacement had increased 12% over that for the cement only sample. The modulus of elasticity (E_{50}) changed in a similar trend as did the stabilized soil strength. Compared with cement alone, the modulus of elasticity of the 30% RHA replacement of cement had increased 13.5% at 28 d.

Microscopic investigation using XRD analysis identified the major reaction products as calcium silicate hydrate (CSH) which played an important role in the stabilized soil strength. It was also found that an increase in the CSH intensity was matched by an increase in the strength development curve. A change in the microstructure of stabilized soil due to phase transfiguration of such major reaction products was illustrated by the SEM observation technique. The use of RHA replacement in cement can be applied in several geotechnical construction works such as soil grouting to increase soil strength for building foundations, soil cement columns to reduce soil settlement and for the improvement of soil bearing capacity for road embankments.

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