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Evaluation of Strength and Microstructure of Adobe Stabilized with Blended Rubber Latex and Sodium Silicate

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ABSTRACT

Adobe stabilized with blended, prevulcanized rubber latex and sodium silicate was developed to enhance the low strength of traditional adobe. Sodium silicate was investigated for its action as a pH stabilizer to maintain the pH and liquidity of rubber latex during the manufacturing process. The study characterized the adobe by its compressive strength, flexural strength and microstructure investigation in terms of surface morphology, chemical analysis, functional groups of molecules and porosity. The results showed that adding 3–5% sodium silicate could preserve the liquidity of 5–10% rubber latex during the mixing process. The study in the functional groups of molecules showed the possibility of sodium silicate as a secondary binder and rubber reinforcement. The investigation of the microstructure of stabilized adobe confirmed that alkaline-stabilized rubber latex could distribute throughout the substrate, bind most of the soil particles and fill the capillary pores when dried. The newly developed sodium-silicate-rubber-clay substrates had better strength when compared with traditional clay adobe, rubber-clay adobe and stabilized rubber-clay adobe with low sodium silicate content. The 3% sodium silicate-10% rubber stabilized adobe had the best performance with compressive strength (3.23 MPa or 237.19% of traditional clay adobe) and flexural strength (1.60 MPa or 298.91% of traditional clay adobe).

Keywords: strength, microstructure, adobe, rubber latex, sodium silicate

INTRODUCTION

Adobe, compacted earth, is one of the oldest building materials used by man that is still commonly used nowadays and at least 50% of the world's population still live in earth-constructed dwellings (Dethier, 1986). Although adobe has provided a reasonable solution to economical living and an eco-friendly considerations, the poor water resistance and the low strength of traditional adobe may cause problems in the service life of adobe walls.

Recent studies have investigated natural rubber latex to improve the mechanical properties and water resistance of adobe (Laokomain, 2004; Ruthankoon *et al*, 2006; Hinchiranan *et al*., 2008). Thailand was the largest exporter and producer of *Hevea brasiliensis* natural rubber in the world from 2005 to 2009 (Rubber Research Institute of Thailand, 2010). Rubber latex has lower embodied energy and better thermal properties than cement-stabilized adobe (Department of Alternative Energy Development and Efficiency, 2007; Ancorn and Wood, 1998; Lienhard IV and Lienhard V, 2008).

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Importantly, rubber latex naturally forms a water soluble binder when dried. However, during the mixing process, rubber latex agglomerates rapidly, forms a film, but subsequently segregates from the fresh substrate (Laokomain, 2004; Ruthankoon *et al*., 2006). Non-homogeneous, rubber-soil substrate can cause difficulty in the molding process (Ruthankoon *et al*., 2006) and can reduce the quality of the rubber-stabilized adobe when dried (Laokomain, 2004)

The colloidal stability of rubber latex is extremely sensitive to pH and the ionic environment of the dispersing medium (Nawamawat *et al*., 2011). The information paper of NOCIL Ltd (2010) stated that if the alkalinity of rubber latex can be maintained by using a fixed alkaline stabilizer (pH stabilizer), the film formation of rubber latex will not proceed.

Sodium silicate has been investigated to improve the properties of rubber-aggregate substrates (Laokomain, 2004; Subsathaphol, 2004; Hinchiranan *et al*., 2008). It acts as a secondary binder (Subsathaphol, 2004; Hinchiranan *et al*., 2008) and also as rubber reinforcement (Subsathaphol, 2004). However, the pH stabilizer characteristics of sodium silicate in enhancing the non-uniformity and mechanical properties of the rubber stabilized adobe have not been mentioned before.

In this research, improvement in the mechanical properties of adobe bricks by using blended rubber latex and sodium silicate was studied using compressive strength and flexural strength testing and also microstructure analysis in terms of the surface morphology (SEM), chemical analysis (EDX), functional groups of molecules (FTIR), and porosity (MIP). The inclusion of high amounts of rubber latex (up to 30%) and sodium silicate (up to 5%) by weight of soil and sand were investigated. Importantly, the pH stabilizer characteristics of sodium silicate in the rubber stabilized adobe are proposed.

MATERIALS AND METHODS

Materials

Sandy clay loam soil was taken from the field in Mae-Rim-Tai subdistrict, Mae-Rim district, Chiang Mai province, northern Thailand. Dried soil lumps were ground and the soil which passed through an ASTM sieve number 10 was used. The properties of soils are given in Table 1. The sand used was fine river sand, following ASTM C778 (ASTM, 2011), collected from the Ping River in Chiang Mai province. The soil-to-sand ratio was fixed at 1:1 by weight.

Table 1 Properties of soil and sand used in the study.

Textural composition of soil	% by weight	Chemical composition	% by weight Soil	% by weight Sand
Sand (0.02–2 mm)	50.74	CaO	1.21	0.87
Silt (0.002–0.02 mm)	22.73	SiO_2	62.50	80.48
Clay (<0.002 mm)	26.53	Al_2O_3	21.50	11.22
pH of soil	6	Fe_2O_3	7.98	2.08
Atterberg limits of soil	%	MgO	1.77	-
Liquid limit (LL)	45.00	K_2O	3.24	5.27
Plastic limit (PL)	28.45	SO_3	0.22	-
Plastic index (PI)	16.55	MnO	0.18	0.08
Shrinkage limit (SL)	22.41	TiO_2	1.37	-
Linear shrinkage (LS)	7.40			

Hevea brasiliensis rubber latex is a commercial casting compound-prevulcanized rubber latex (R), which has common formula as shown in Table 2. The sodium silicate (SS) used was commercial 90% industrial graded sodium silicate (Na_2SiO_3) with 4% water content. The pH value of the sodium silicate was 13. Tap water with a pH value of 7 was used.

Specimen preparation and investigating on fresh mixture

The mix proportions are summarized in Table 3. Soil and sand were mixed in a dry state for 5 min at low speed in a mortar mixing machine and then mixed with water on medium speed for 3 min. To stabilize the adobe, sodium silicate was mixed with water before pouring into the soil-sand

Table 2 Compounding ingredients of casting compound-prevulcanized rubber latex.

Type	Weight (g)	Function
Concentrated rubber latex (60% Dry rubber content)	167	Rubber
50% Sulfur dispersion	5	Vulcanizing agents
50% ZnO dispersion	3	Activators
50% ZDEC dispersion	3	Accelerators
50% ZMBT dispersion	2	Accelerators
10% Teric 16 A16	2	Non-ionic wetting agent (Surfactants)
50% TiO_2	5	Fillers & pigments
50% $CaCO_3$	20	Fillers
50% Wingstay-L	2	Antioxidants
pH		10

Table 3 Mix proportions of adobe.

Stabilizer		Notation
Type	Contents (% by weight of soil & sand)	
Traditional adobe	-	R0
Rubber	R = 5, 10, 20, 30 %	R5, R10, R20, R30
Sodium silicate	SS = 0.2, 0.4, 0.8, 1.5, 3 %	SS,0.2, SS0.4, SS0.8, SS1.5, SS3
5% Rubber + Sodium silicate	R = 5% with SS = 0, 0.5, 1, 3, 5	R5_SS0, R5_SS0.5, R5_SS1, R5_SS3, R5_SS5
10% Rubber + Sodium silicate	R = 10% with SS = 0, 1, 3, 5	R10_SS0, R10_SS1, R10_SS3, R10_SS5

dry mix and the rubber latex was added last. Water (about 0.16–0.25% by weight of soil and sand) was added to provide a practical fresh adobe with an initial flow of 60–70%, according to ASTM C1437 (ASTM, 2011). During the mixing process, the film formation of rubber latex was also observed by visual inspection.

After finishing mixing, the pH of the fresh mixture was measured. Then, the fresh mixture was placed immediately in a mold and manually compacted. The fresh mixture was poured into the mold in two layers and each layer was tamped 32 times to ensure uniform filling of the mold.

The adobe mixtures were sun dried in the molds and the molds were removed after 1–2 d. Specimens were sun dried for a further 3 d and then oven dried at 60 °C for 4–7 d until constant weight before testing. The moisture content of specimens was around 2% which was in the range 2–5% for the equilibrium moisture content of adobe materials (Morton, 2008).

Compressive strength test

The average compressive strength of all mixture proportions was calculated from a sample of five 5 × 5 × 5 cm blocks, according to ASTM C109 (ASTM, 2011).

Flexural strength test

The average flexural strength of all mixture proportions was calculated from a sample of three 4 × 4 × 16 cm blocks, according to ASTM C348 (ASTM, 2011).

Scanning electron microscopy-energy dispersive X-ray spectrometry

The morphology of the samples was investigated using a scanning electron microscope (JSM 5910 LV; JEOL Ltd.; Tokyo, Japan) with gold coating and an energy dispersive X-ray spectrometer (EDX) attached to this instrument was used for semi-quantitative chemical analysis.

Porosimetry

The porosity (% specimen volume) and pore size distribution of the samples were measured on brick fragments weighing less than 1 g using an Hg porosimeter (PO2000; Carlo Erba Instrumentazione; Milan, Italy) with a macropore unit. The maximum pressure reached during the analysis was 800 bars.

Fourier transform-infra red spectroscopy

A Fourier transform-infra red spectroscopy (FTIR) microscope (Nicolet 6700 FTIR-microscope; Thermo Fisher Scientific, Inc.; Waltham, MA, USA) was used to study the functional groups of molecules of soil stabilized with sodium silicate and prevulcanized rubber latex.

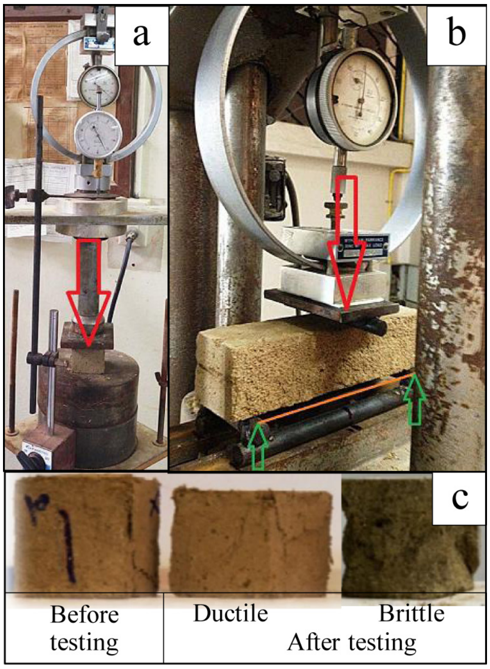


Figure 1 Testing procedure and failure modes in compression: (a) Compressive strength test, (b) Flexural strength test; (c) Failure modes in compression.

RESULTS AND DISCUSSION

Investigations on fresh stabilized adobe

The pH values of fresh adobe and the rubber film formation in fresh plaster were investigated. The soil and traditional adobe had pH values of 6 while the sodium silicate and rubber latex had pH values of 13 and 10, respectively. When rubber latex was added to fresh adobe, a rubber film formed rapidly on the rubber aggregate (smaller than 5 mm in this study), similar to the reports by Laokomain (2004) and Ruthankoon *et al*. (2006). The segregation increased when the rubber latex content increased above 5%. The pH value of these rubber-stabilized adobes was 6. The decreasing pH value of rubber latex is one reason for this early film formation (Subsathaphol, 2004).

When high amounts of sodium silicate (equal to or greater than 3%) were added to the adobe mixture, the fresh sodium-silicate-stabilized adobe had a strong alkaline pH value of 10 or higher. When the rubber latex was added last, the pH values of the fresh sodium-silicate-rubber-stabilized adobe, such as R5_SS3, R10_SS3 and R10_SS5 (see Table 3 for notation description), were still not less than 10. Therefore, during the manufacturing process, the rubber latex did not form a film or small rubber aggregates because the alkalinity of the rubber latex was maintained by the 3-5% sodium silicate as a pH stabilizer (NOCIL Ltd, 2010).

Compressive strength and flexural strength results

Influence of rubber latex content

The strength characteristics of rubber-stabilized adobe are shown in Figure 1. The results revealed that adding rubber latex up to 5% increased the compressive strength from 1.36 to 1.52 MPa at 11.95%. The binding and confinement ability of the rubber film are the reasons for this improvement. However, more than 5% rubber latex decreased the compressive strength. During the mixing process, it was observed that the excess rubber latex tended to increase the amount of small, soft rubber aggregate resulting in reduced strength. Another reason for the reduced strength was that the increase in the amount of rubber latex increased the thickness of the film covering the soil particles, resulting in softening of the surface around the soil particles (Khamput and Suweero, 2011). These compressive results agreed well with those reported by Parichatprecha *et al*. (2013). Similar to the compressive strength results, the flexural strength results of rubber-stabilized adobe

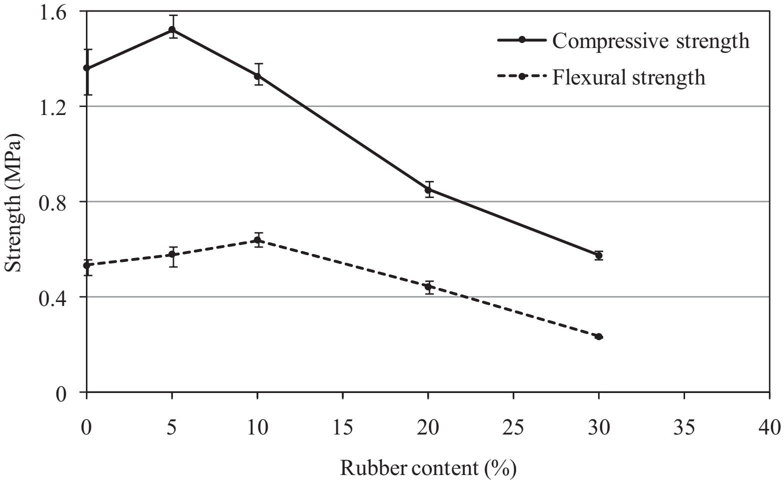


Figure 1 Compressive and flexural strength of rubber stabilized adobe. (Error bars show maximum and minimum values.)

showed the same trends with a 10% optimum rubber content. Adding rubber latex up to 10% increased the flexural strength from 0.54 to 0.64 MPa at 19.17%. Moreover, the failure mode of the rubber-stabilized adobe was more ductile and had a higher deformation than the brittle traditional clay adobe one, as shown in Figure 1, due to the tensile and elastic properties of rubber films.

Influence of sodium silicate content

As shown in Figure 2, adding sodium silicate in the adobe mixture can substantially improve both the compressive and flexural strength with an optimum content of 0.8% sodium silicate. An increase in the sodium silicate content from 0% to 0.8% could increase the compressive strength from 1.36 MPa to 2.97 MPa, which was 218.24% of the compressive strength of traditional clay adobe. Similarly, an increase in the sodium silicate content from 0% to 0.8% could increase the flexural strength from 0.54 MPa to 1.03 MPa, which was 192.13% of the flexural strength of traditional clay adobe. However, the improvements in the compressive and flexural strength tended to drop after increasing the sodium silicate to more than 0.8%.

The effect of sodium silicate on the compressive and flexural strength of sodium-silicate-stabilized adobe can be explained by the effect of silica gel (the condensation of sodium silicate) which can consolidate the matrix by its bonding ability (Ren and Kagi, 1994). From such behavior, a much greater volume of formed silica gel can cause a decrease in the density of stabilized plaster and reduce the enhancement of compressive and flexural strength (Banjongkliang *et al*., 2015).

Influence of addition of rubber latex and sodium silicate

The addition of 5-10% rubber latex was further studied with the combination of sodium silicate. The strength characteristics of adobe stabilized with blended 5% or 10% rubber and 0–5% sodium silicate (R5_SS adobe and R10_SS adobe), are shown in Figure 3 and have the same trends. Adding sodium silicate up to 5% could improve the strength of rubber-stabilized adobe with the maximum strength achieved with the addition of 3% sodium silicate. An increase in the sodium silicate up to 1% increased the compressive strength of 10% rubber-stabilized adobe from 1.33 MPa of R10_SS0 to 1.87 MPa of R10_SS1. This may have been due to the increase in the bonding of the condensation of sodium silicate as mentioned earlier. Excess sodium silicate above 1% (SS1.5 and SS3) reduced the compressive strength of sodium-silicate-stabilized adobe,

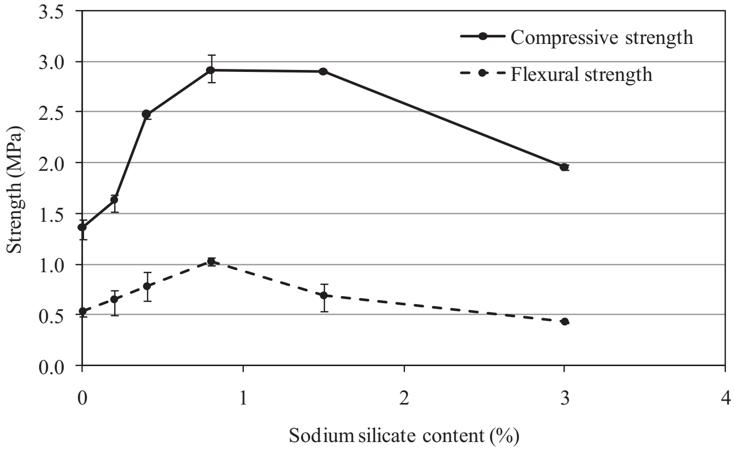


Figure 2 Compressive and flexural strength of sodium-silicate-stabilized adobe. (Error bars show maximum and minimum values.)

whereas in contrast, adding 3% sodium silicate to rubber-stabilized adobe (R10_SS3) substantially increased the compressive strength of R10_SS0 adobe from 1.33 MPa to 3.23 MPa or 237.19% of traditional clay adobe. One of the reasons for this improvement was that alkaline-stabilized rubber latex can be fully dispersed and evenly distributed in the mixture during the manufacturing process. Subsequently, alkaline-stabilized latex film can occupy the voids and microstructural cracks in the hardened substrate (Muhammad *et al*., 2012). Moreover, evenly distributed alkaline-stabilized rubber can bind most of the soil particles as shown later. However, an increase in the amount of sodium silicate to more than 3% tended to reduce the compressive strength of the sodium-silicate-rubber-stabilized adobe due to the excess volume of soft formed silica gel (Banjongkliang *et al*., 2015). The R10_SS3 adobe had the highest compressive strength (3.23 MPa) which was 11.13 times greater than the maximum compression stress (0.29 MPa) at the base of an adobe wall in a two-storey structure (Quagliarini *et al*., 2010)

Similar to the compressive strength results, the flexural strength results of sodium-silicate-rubber-stabilized adobe had the same trends with a 3% optimum sodium silicate content. The maximum flexural strength obtained from R10SS3 was 1.60 MPa or 298.91% of traditional clay adobe.

Results of scanning electron microscopy-energy dispersive X-ray spectrometry analysis

The morphology of the traditional clay adobe (R0) and sodium silicate stabilized adobe (Figures 4a and 4d, respectively) clearly present clay platelets and larger SiO_2 particles with rough and porous surface. The presence of high amounts of Si with Al in the EDX analysis provided evidence of clay platelets in the substrate (Figure 4a), while the presence of C in R0 (Figure 4a) was much lower than in hydrocarbon, rubber-stabilized adobe (Figure 4b and Figure 4c).

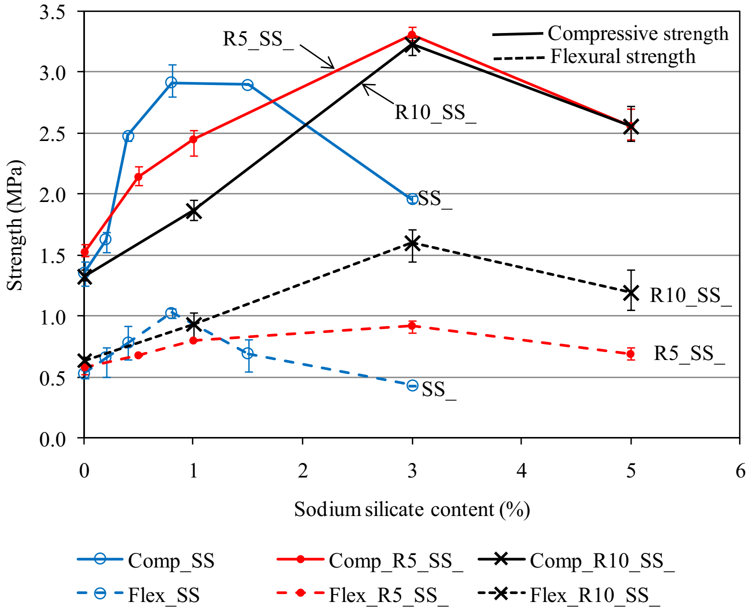


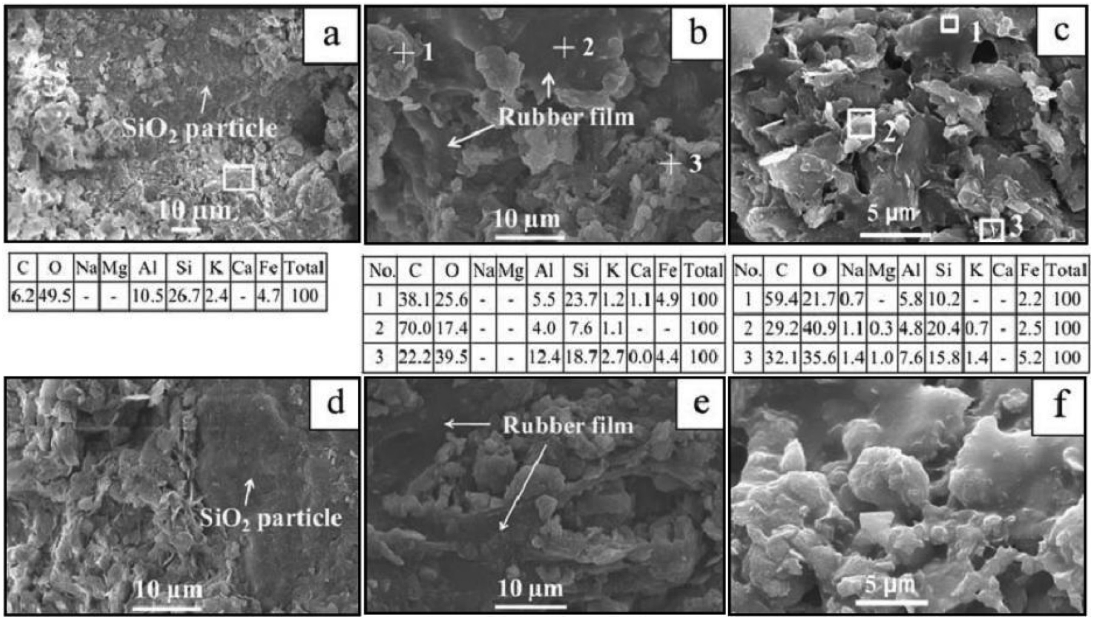
Figure 3 Compressive and flexural strength of adobe stabilized with sodium silicate and with blended rubber and sodium silicate. (See Table 3 for descriptions of the legend terms. Error bars show maximum and minimum values.)

The morphology of rubber-stabilized adobe (R10 and R10SS1 in Figures 4e and Figure 4b, respectively) showed a large, thick rubber film wrapping only some groups of SiO_2 particles. The rubber film had a relatively smooth surface compared with the rough surface of traditional clay adobe. In the EDX analysis (Figure 4b), the wide range in the C content (22.2–70.0%) provided evidence of a hydrocarbon rubber film with a non-uniform distribution in the substrate.

The morphology of R10SS3 and R10SS5 (Figures 4c and 4f, respectively), in which sufficient sodium silicate had been added to act as a pH stabilizer, clearly presented a better distribution of thin, smooth-surfaced rubber films throughout the substrates. These figures clearly show that thin rubber films covered most of the substrate surface and it may be assumed that this thin rubber film could bind most of the soil particles and also fill the voids in the substrate. In the EDX analysis of R10SS3 (Figure 4c), the presence of a high amount of C (29.2–59.4%) confirmed the evidence of the rubber film in the substrate, while the presence of Na provided evidence of sodium silicate in the substrate. Importantly, the ranges of C and Si in R10SS3 were narrower than in R10SS1 perhaps because of the more uniform distribution of alkaline-stabilized rubber film and could confirm the success of the liquidity preservation of rubber latex by using the 3–5% sodium silicate as a pH stabilizer during the mixing process.

Results of Fourier transform-infra red spectroscopy analysis

The FTIR study of the 24 hr-dried sodium silicate (SS) in Figure 5 shows the typical peaks of sodium silicate and indicates the reaction of the sodium silicate hardening process with CO_2 (from the air) according to the study of Bobrowski *et al.* (2012). The strong band of SS is located at 955 cm^{-1} with two shoulders at around 1,049 and 868 cm^{-1}. The main bands at around 955 cm^{-1} and 868 cm^{-1} indicate the presence of Si-O stretching vibration of mostly $[SiO(OH)_3]^-$ and $[SiO_2(OH)_2]^{2-}$ species as the main silicate network group. The bands between 400 and 600 cm^{-1} can be



C	O	Na	Mg	Al	Si	K	Ca	Fe	Total
6.2	49.5	-	-	10.5	26.7	2.4	-	4.7	100

No.	C	O	Na	Mg	Al	Si	K	Ca	Fe	Total
1	38.1	25.6	-	-	5.5	23.7	1.2	1.1	4.9	100
2	70.0	17.4	-	-	4.0	7.6	1.1	-	-	100
3	22.2	39.5	-	-	12.4	18.7	2.7	0.0	4.4	100

No.	C	O	Na	Mg	Al	Si	K	Ca	Fe	Total
1	59.4	21.7	0.7	-	5.8	10.2	-	-	2.2	100
2	29.2	40.9	1.1	0.3	4.8	20.4	0.7	-	2.5	100
3	32.1	35.6	1.4	1.0	7.6	15.8	1.4	-	5.2	100

Figure 4 Scanning electron microscopy micrographs (with energy dispersive X-ray spectrometry analysis for a–c): (a) R0 (b) R10SS1 (c) R10SS3 (d) SS3 (e) R10 and (f) R10_SS5 adobe. (See Table 3 for descriptions of the sample notation.)

attributed to the rocking motion of the Si-O-Si bridges. The bands between 2100 and 2400 cm^{-1} can be attributed to the vibrations of the hydrogen bridges between $Si(OH)_4$ and the silicate lattice. The band between 2700 and 3600 cm^{-1} and the band at 1651cm^{-1} could be attributed to unbonded water molecules and OH– bending and stretching modes. In addition, the band at 1390 cm^{-1} corresponds to the asymmetric stretching vibration of O-C-O bonds. The band at 1651 and 1390 cm^{-1} indicates the reaction in the sodium silicate hardening process with CO_2 from the air (Rabbii, 2001: Bobrowski *et al*., 2012). The band at 1390 cm^{-1} also confirms the possible condensation of sodium silicate in mud brick as explained by Ren and Kagi (1994). However the band at around 1390 cm^{-1} did not appear in the FTIR study of SS3 adobe because only a small amount of 3% SS was added to the clay adobe (Figure 6). The R0 and SS mostly had similar spectra because they contained most of the SiO_2 (Figure 6).

The typical polyisoprene peaks of prevulcanized natural rubber (R) are clearly visible in Figure 5. Bands were observed at 1662 cm^{-1} for C=C– stretching vibration, 1444 and 1375 cm^{-1} for CH_2 bending vibration, 840 cm^{-1} for C–H bending vibration and from 2959 to 2852cm^{-1} for C–H saturated stretching vibration, according to Yahya *et al.* (2011). The additional bands in the range of 1171–935 cm^{-1} indicated the presence of the content of C-S stretching vibration in the vulcanization system, according to Yahya *et al.* (2011) and Gunasekaran *et al.* (2007).

The FTIR study of R10/SS3 film (rubber:sodium silicate:water = 10:3:25 by weight in fresh mix) presented the characteristic bands of hardened, prevulcanized, natural rubber film and hardened sodium silicate and also identified the interaction between the sodium silicate and natural rubber matrix (Figure 5). The main bands of natural rubber were observed in the ranges 1375–1444 cm^{-1} and 2850–2960 cm^{-1} as described previously. In addition to these characterization peaks of natural rubber, the characteristic bands of sodium silicate were clearly observed at around 1022, 1400 and 3310 cm^{-1}. These results verified the availability of the sodium silicate in the rubber phase. The bands at around 1400 cm^{-1} and an increase in the intensity of the peak at around 1651 cm^{-1} verified the possible condensation

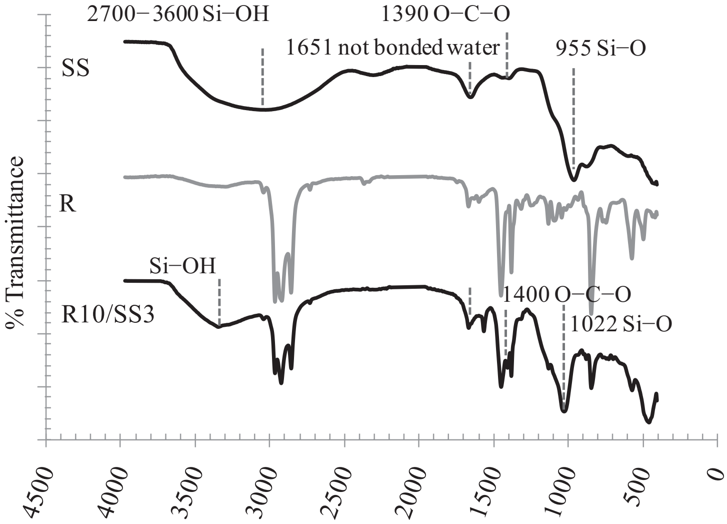


Figure 5 Results of Fourier transform-infra red spectroscopy for sodium-silicate-stabilized rubber film. (See Table 3 for descriptions of the sample notation.)

of sodium silicate as a secondary binder in the rubber film, which agreed well with those reported by Subsathaphol (2004) and Hinchiranan et al. (2008). The band at around 1000 cm^{-1} verifies the availability of silicate which acts as silica-reinforced rubber (Subsathaphol, 2004). From this study, it can be concluded that sodium silicate can act as an inert filler in rubber film and as a secondary binder in rubber-stabilized adobe.

As shown in Figure 6, the FTIR study of traditional clay adobe (R0) identified quartz and clay minerals such as kaolinite and illite in the substrate according to Nayak and Singh (2007). In this study, Si–O stretching vibrations were observed at 796 cm^{-1}, 693 cm^{-1}, 523 cm^{-1} and 456 cm^{-1}. These bands showed the presence of quartz. The strong bands at 1001 and 911 cm^{-1} and the bands at 3697, 3623 and 3450 cm^{-1} mostly indicated the presence of kaolinite and illite, respectively.

Finally, the FTIR study of R10SS3 in Figure 7 shows some small peaks of natural rubber at 1444, 1375 cm^{-1} and in the range 2959–2852cm^{-1} in the spectral pattern of the mostly SiO_2 clay adobe. This result verified the existence of sodium-silicate-stabilized rubber film in the matrix of the stabilized adobe.

Results of porosimetry analysis

Only capillary porosity (0.01–10 µ) was considered in this study. The porosity results of small pores (<0.01 µ) were too small (<0.32%) and could be neglected (Banjongkliang and Stitmannaithum, 2006). Moreover, the porosity results of the bulk pores, which were not entirely detected by MIP, were too variable to study comparatively (Banjongkliang and Stitmannaithum, 2006).

Figure 8 also shows the results for the SS-rubber-clay adobe where increasing the 3–5% sodium silicate content with the pH increasing to more than 10 clearly reduced the capillary porosity of the stabilized adobe. The results agreed with previous results in this study where as the SS increased from 3%, the fresh liquid rubber-clay adobe could evenly distribute throughout the substrate to fill the pores and bind most of the particles during hardening. Subsequently, the compressive and flexural strength were substantially increased.

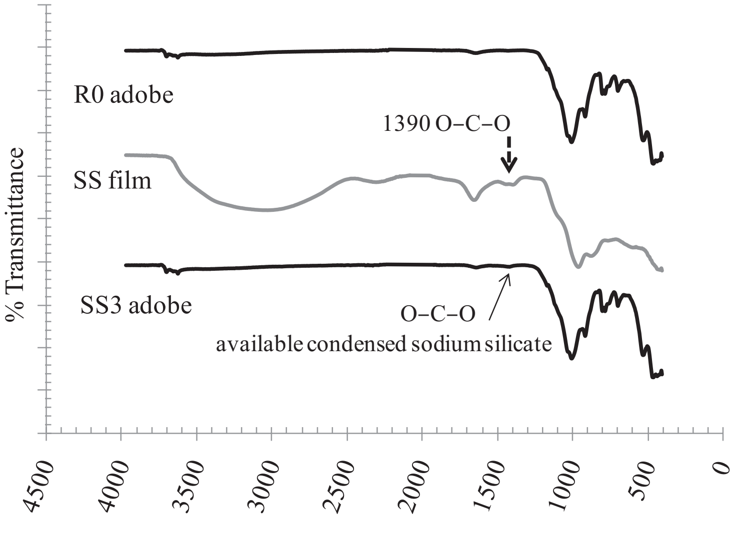


Figure 6 Results of Fourier transform-infra red spectroscopy for sodium-silicate-stabilized adobe. (See Table 3 for descriptions of the sample notation.)

CONCLUSION

Adding 5-10% of prevulcanized rubber latex to traditional clay adobe could improve its compressive and flexural strengths due to the binding and confinement ability of the rubber film. However, small rubber aggregate formed during the mixing process and can reduce the mechanical properties of stabilized adobe when dried. Moreover, the rubber film could hold only some clusters of soil particles.

Adding 3–5% sodium silicate can act as a pH stabilizer to maintain the pH at 10 in the rubber latex and to preserve the liquidity of the rubber latex when mixed with other ingredients. Subsequently, stabilized rubber latex could evenly distribute over the adobe matrix. When the stabilized adobe dried, the alkaline-stabilized rubber films could substantially reduce the voids from 20.49% in traditional adobe to 13.81% in the 3% sodium silicate-10% rubber stabilized adobe. These stabilized rubber films could clearly bind

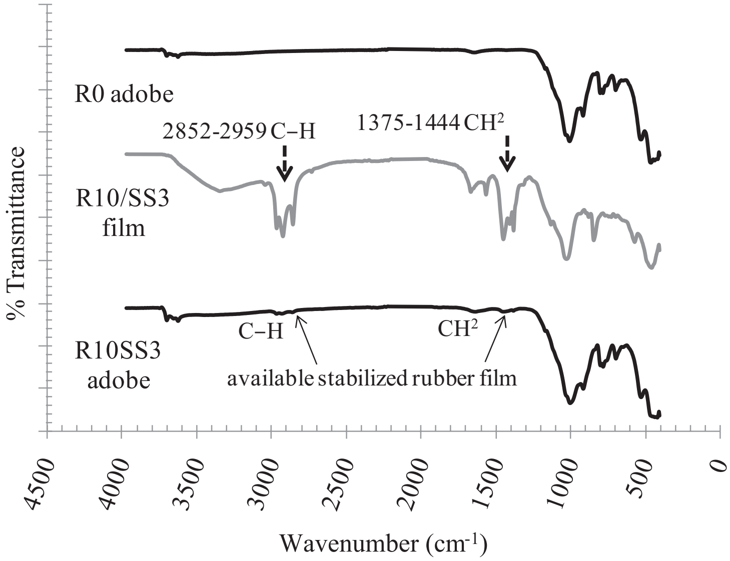


Figure 7 Results of Fourier transform-infra red spectroscopy for sodium silicate-rubber stabilized adobe. (See Table 3 for descriptions of the sample names.)

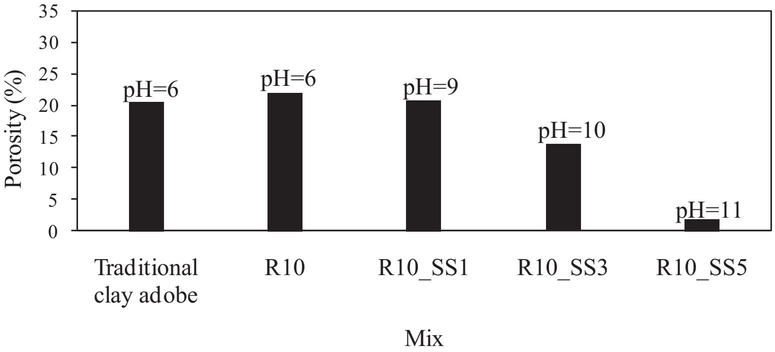


Figure 8 Capillary pore volume of hardened stabilized adobe with its pH value when fresh. (See Table 3 for descriptions of the sample notation.)

most of the soil particles throughout the substrate according to the SEM analysis. Moreover, adding 3–5% sodium silicate can act as a secondary binder and rubber reinforcement as was found in the FTIR analysis. Therefore, these newly developed sodium-silicate-rubber-clay substrates had the best performance in compressive and flexural strength compared with traditional clay plaster, rubber-clay plaster and stabilized rubber-clay plasters with low sodium silicate contents.

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