An investigation of lateritic Soil Cement for Sustainable Pavements

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Abstract

Shortage of crushed rock as pavement base course for road construction and an increase in fuel cost have prompted the search for alternative materials. In this regard, improvements of the lateritic soil cement (LSC) have been investigated. The production of crushed rock involves drilling, blasting, crushing and transportation, which are the cause of environmental problems. The objective is to use the improved lateritic soil instead of crushed rock as the base course material for highway pavement construction. In order to understand why the LSC has higher strength, microstructure of LSC composite was investigated by X-ray diffraction machine (XRD) and the Scanning Electron Microscope (SEM). The improvement of the unconfined compressive strength (UCS) of LSC composite was also evaluated. As regards the application aspect, the results shows that cement mixed lateritic soils are suitable for base course construction. Even though properties of stabilized soils have been widely studied in many countries, there are still no general agreements as to which mechanism that can best illustrate how the stabilized soil's properties are improved. The present study investigated, among other properties, the strength parameter of the stabilized soil sample as more stabilizing binder was added. It was found that as the amount of the added chemical, calcium silicate hydrate (CSH) increased, the Unconfined Compressive Strength (UCS) of the sample also exhibited corresponding increase.

Keywords: lateritic soil, crushed rock, cement, sustainable pavements, stabilization

1. Introduction

Roads are main consumers of aggregate and the influence of aggregate cost is added in total construction cost of the roads. In India, use of recycled aggregate from building waste has been studied with the purpose of reduce the material cost (Gopala Raju *et al.*, 2010). Similar to this study, the improvement of lateritic soil with cement mixing was modified for base course materials to improve performance. There are many reasons for using LSC, ranging from lack of crushed rock to a desire to reduce crushed rock usage for environmental reasons. The locations of Quarry sites for crushed rocks for road construction are getting more difficult to access and are depleted in many areas of Thailand. The costs of transportation materials from further away may also increase, thus compounding the problem. Another reason for using the LSC is the financial and environmental cost of energy used in the production stage of such highway materials. The increased awareness of environmental impacts has lead to some restrictions being imposed on extraction of natural resources. The crushed rock production process consumes a considerable amount of energy for mining, transportation, burning and which contributes to the total CO_2 emissions to the atmosphere. The environmental issues to be addressed include the need to reduce the levels of CO_2, emissions. Low cost and environmental friendly features are the added benefit of the stabilization.

Lateritic soils are soil types rich in iron and aluminum, distributed in many areas of the world. It is not suitable for const1uction of base course. The selected materials such as crushed rock are usually used for this purpose. The production of crushed rock aggregate involves drilling, blasting, crushing and transportation which can create serious environmental problems. With suitable additive, properties of lateritic soil can be improved. Ordinary Portland cement type 1 is one of the most suitable materials used for road stabilization (Ruenkrairergsa T, 1982; Anon, 1990; Mitchell JK, 1981).

Portland cement was mixed with the soil at a mix proportion 3, 5, 7 and 9% by weight of dry soil, used water content at the optimum moisture content (OMC). Modified compaction specimens were prepared for UCS tests at curing times of 3, 7, 14 and 28 days, respectively. Method of XRD and SEM were performed to investigate the development of microstructures, chemical components and mineral components of soil cement, respectively. The objective of this paper was therefore to investigate major hydration products which contribute of the strength development of LSC by using UCS. Since lateritic soil was mixed with cement for economical and environmental propose, the cement content in the additive should be as low as possible. The appropriate ratio was obtained from UCS not less than 1. 721 MPa in accordance with Department of Highways Thailand.

2. Materials and method

Lateritic soil was collected from a site at Hatyai in Thailand about 0.5-2.0 m depth below the ground surface. The lateritic soil was sealed in the air tight plastic containers and transported to the laboratory for testing. These lateritic soil samples have the following distribution: percent passing sieve No.200 and No.4 are 10.6% and 51.8%, respectively. The basic properties from Atterberg's limit test are as follows: LL=50% and PI=l5.8%. According to unified classification system, the soil can be classified as clayey sand (SC) which has percent of gravel 49.2% or it can be classified as clayey sand with gravel. For AASHTO soil classification, it can be identified as A-2-7 which is Clayey Gravel Sand.

Portland cement is one of the most common binders used in soil stabilization. In chemical stabilization, the binder, either cement or lime is added to the problematic soil which requires improvement in its properties. The binder, in this case, cement is then thoroughly mixed with the soil, while the required amount of water is added to help with the hydration process. The mixture called soil-cement is then compacted in-situ in the specified time and allowed to harden. Factors that influence physical properties of the soil-cement include soil type, amount of added cement, degree of mixing, time of curing, degree of compaction and moisture content (Anon, 1990). The mechanism which the added cement improves the soil properties can be explained as follows: firstly, it breaks up the soil mass by reducing the soil plasticity, it is especially effective with soil possessing high content of clay particles; the reduction of soil plasticity enables the increase of mixing efficiency. With added water, cementation process was activated, which results in the increase of the strength and other properties of the clayey soil. For fine grain silty and clayey soils, cementation, occurred as a result of hydration of cement, creates a matrix of soil aggregates with strong bonds between them. The stabilized soil matrix obtains its strength from a honeycomb-like structure which is effective in confining the soil particles to disable their sliding motion over one other. Furthermore, the effect of the surface chemical of the cement is to reduce its affinity for water, hence, the water holding capacity of soils. The reduction in water affinity and water holding capacity together with a strong matrix help solidify the soil aggregates with the resulting increase in strength of the stabilized soil (Huangjing S and Gasaluck W, 2010).

In case of LSC, compaction tests were run on the lateritic soil and cement with water content of 2, 4, 6%, 8% and 10% to find the amount of water which gave the maximum dry density. The appropriate amount of water at each amount of cement content was employed for UCS tests. Each specimen was prepared using cylindrical mold having inner diameter of 101.6 mm and height of 116.8 mm. The prepared soil was placed in the cylindrical mold in five layers and each layer was compacted according to the procedure of modified Proctor compaction. After compaction, the specimens were wrapped with plastic sheet and cured at room temperature and submerged under water for 2 hours before testing. The UCS of the composite soil cement was determined at various curing ages.

3. Results and discussions

A quantitative assessment of soil mineral composition was performed using X-ray Diffractometer, XRD, PHILIPS X'Pert MPD, Netherlands. XRD analysis was conducted at 7 curing days to evaluate the minerals transformation at 3% cement content. The XRD patterns of LSC before and after mixing are shown in Fig.1 and Fig.2, respectively. In general, minerals composition from XRD results can be categorized as clay minerals, non-clay minerals, and additive and new reaction products. Mineralogy plays an important role in establishing the character of a lateritic soil.

The clay minerals found in the lateritic soil samples is kaolinite ($Al_2(Si_2O_5)(OH)_4$) whereas the non-clay minerals are quartz (SiO_2) and calcite ($CaCO_3$) Calcium carbonate is a chemical compound with mineral group of Carbonates.

Fig.1. *X-ray diffraction pattern for lateritic soil-cement before mixing*

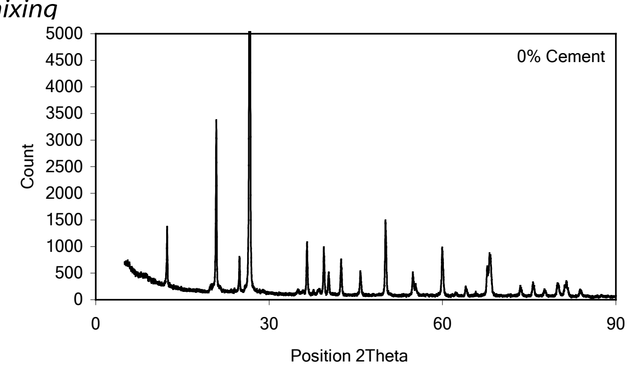
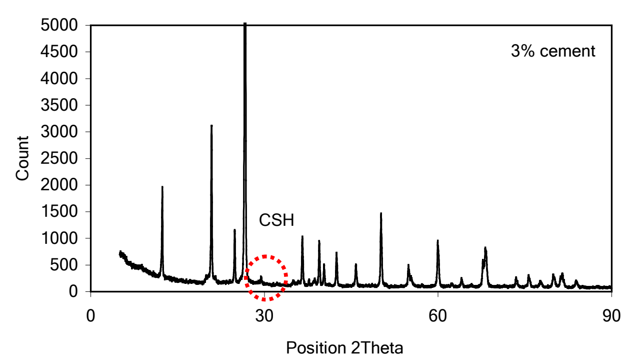


Fig.2. *X-ray diffraction pattern for lateritic soil-cement after mixing*



The XRD pattern of 3% cement showed that the calcium silicate hydrate (CSH) intensities was produced due to the cement mixture. The results from XRD analysis showed that cementitious products (CSH) were main reaction products contributing of strength development of the stabilized lateritic soils.

The pictures of the soil microstructure before and after treatment by the SEM are shown in Fig.3 and Fig.4, respectively. It appears that the soil cement composite can be seen in separate lumps as shown in Fig.4. The micrograph shows flanky arrangements of clay particle (Kaolinite) as matrix between the fine grains. The soils were being coated and bound by the silicate gel. The gels cementd the particles to form aggregated crumbs. The cementation products formed were identified by XRD known as CAH and/or CSH. The soil cement mixtures micrographs illustrate the new phase consists of an interlocking network.

Cement stabilization involves the following of 3 processes: cement hydration; cation exchange reaction and pozzolonic reaction carbonation (Anon, 1990; Mitchell JK, 1981). The strength of the stabilized soil increases with time due to pozzolanic reaction. Calcium hydroxide in the soil water reacts with the silicates and aluminates (pozzolans) in the soil to from cementing materials or binder, consisting of calcium silicates and/or aluminate hydrates.

Fig.3. *SEM of lateritic soil before mixing*

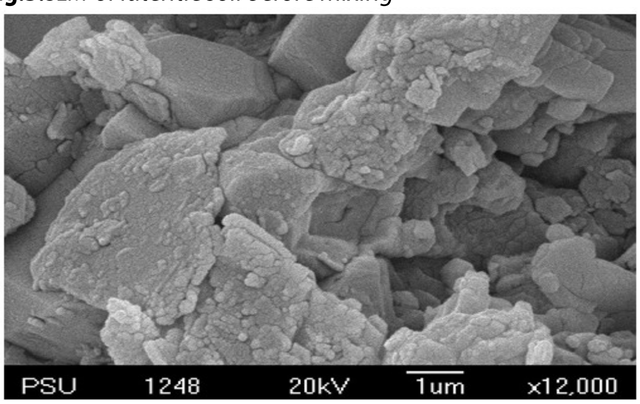


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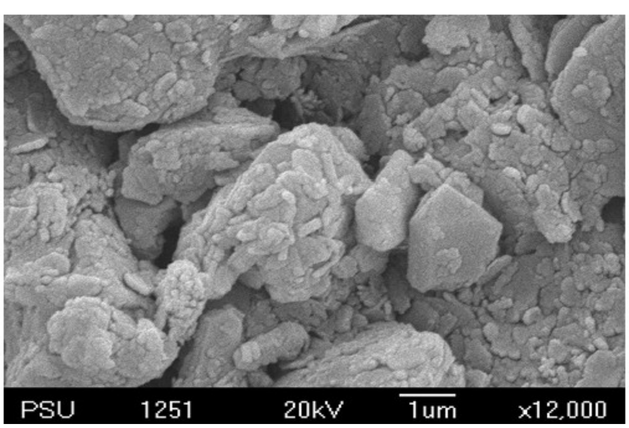
Fig.4. SEM *of lateritic soil after mixed with 3% cement*



The results from SEM observations, microstructures of the LSC changed through the processes of stabilization. It revealed that the structure of 3% cement was relatively denser that untreated soils. The SEM observation showed significant change in soil structures. It revealed that their structures had high void ratio. After stabilizing process, the soil's particles become flocculated, resulting in reduced void ratio.

Table1 shows the UCS of LSC samples stabilized by cement at the curing ages. It can be seen that the UCS increased with increasing cement content as well as with increasing time of the curing. The increase of the UCS was thus large when the cement content was high. The mix contained 3% cement, 7 and 28 days UCS test samples gave strength of 2.22 MPa and 3.39 MPa, respectively. It was also noted that laboratory prepared samples produce a 7 days strength over 1.72 MPa complying the specification of Department of Highways Thailand for base course materials. The initial increase of the UCS of the LSC composite was mainly caused by a reduction of the water content due to hydration. The increase of the UCS was still large even after 28 days due to ion exchange and cementation.

Table 1. *Results of test series*

Test#	Cement content (%)	Curing time (days)	Dry density (kN/m^3)	UCS (MPa)
1	3	3	20.92	1.86
2	5	3	20.92	3.41
3	7	3	21.69	5.08
4	9	3	21.10	5.99
5	3	7	20.91	2.22
6	5	7	21.53	3.84
7	7	7	21.52	5.36
8	9	7	21.00	6.54
9	3	14	21.08	2.42
10	5	14	21.42	4.48
11	7	14	21.87	6.04
12	9	14	20.98	7.22
13	3	28	21.33	3.39
14	5	28	21.42	5.36
15	7	28	21.60	6.77
16	9	28	21.12	8.16

4. Economic analysis of cement stabilised base

The cost comparison between crushed rock base and lateritic soil cement base are given in Table 2. Lateritic soil cement base is relatively cost effective. In this highway works, analysis indicated that lateritic soil cement base will be cheaper than crushed rock base about 48% of area 44 m^2. It was also found that the most expensive item is the cost of cement, about 39.7% of total cost. The use of lateritic soil cement pavement maintenance for the highway construction project in Thailand is shown in Fig.5.

Table 2. *The cost comparison between crushed rock base and lateritic soil cement base*

List	Unit	Amount	Cost (USD)	
			Lateritic soil	Crushed rock
Material	m^3	10	61	316
Cement	bag	12	68	-
Backhoe-loader	hr.	1	10	10
Water truck	day	1	31	31
Total cost	USD		171	358
Unit cost	USD/m^2		4	8

Fig.5. *Pavement maintenance using lateritic soil cement*

It is clear that the cost of crushed rock has increased by a considerable amount due to the impact of the energy and environmental charge. The cost escalation problems and environmental impacts have promoted research on and development of the performance of local materials in terms of strength, cost, energy consumption, manufacturing, transportation and the environmental concerns.

5. Conclusions

Stabilisation is the process of mixing cement with a lateritic soil to produce a material whose strength is greater than that of the original material. The use of stabilisation to improve the properties of a material is becoming more widespread due to the increased strength. The Ordinary Portland Cement (Type I) could be effectively used to stabilize lateritic soil with a suitable mixing content. It could be concluded that formations of these reaction product were substantially influenced by cement content, which was confirmed by XRD patterns, SEM micrographs and UCS results. The strength increases proportionally with increasing cement content. In conclusion, stabilized lateritic soil can be used as road base course. Only about 3% by weight of the Portland cement is enough to stabilize lateritic soil to meet the Department of Highways specification and can be an economical substitution for crushed rock. Furthermore, the use of stabilized lateritic soil decreases environmental problems in decreasing demand on crushed rock.

6. Acknowledgments

The Authors wish to express the profound gratitude to Department of Highways, Thailand. The authors would like to thank all the staffs of the highway construction route number 2160 for their diligence works.

7. References

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