STABILIZATION OF CLAYEY SAND USING FLY ASH MIXED WITH SMALL AMOUNT OF LIME

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ABSTRACT : This study aims to use fly ash mixed with small amount of lime to improve properties of soil. Clayey sand (SC) classified by the USCS was prepared by mixing sand and clay in the proportion of 88:12. The soil represents the lowest permissible clay fraction in this category. Results indicate that SC has satisfied required physical properties for geotechnical construction such as bottom liner for landfill, while some engineering properties must be improved such as shear strength and hydraulic conductivity. A proportion of lime to fly ash of 1:20 was selected based on compaction results giving the highest maximum dry density (MDD). SC was then mixed with this proportion at stabilizer contents of 3, 6 and 10 percent by dry weight.

The samples were prepared by standard compaction with varying water content from optimum moisture content (OMC) to two percent wet of optimum (OMC+2%). Hydraulic conductivity and strength samples were prepared in a size of ∅4″x4.6″ and ∅2″x4″, respectively. Hydraulic conductivity tests were performed by constant head method after curing time of 14 and 28 days. Strength test samples were cured for 7, 14, 28 and 90 days and divided into 2 groups (unsoaked and soaked samples) before performing by unconfined compression tests.

Results show that SC compacted at OMC and OMC+2% has hydraulic conductivity of 9.75×10^{-6} and 1.13×10^{-7} cm/sec, respectively. SC mixed at 10 percent stabilizers and compacted at OMC can achieve low permeability of 1×10^{-7} cm/sec. For strength test results, soaked SC is slaked for all cases during soaking (2 hours) and unsoaked SC has strength of 0.11-0.24 kg/cm^2. Results suggest that use of 6-10 percent stabilizers can satisfy strength requirement for some geotechnical construction such as bottom liners for landfills. Relationship among strength loss, hydraulic conductivity and amount of additives indicates that amount of stabilizers significantly reduces the hydraulic conductivity resulting in reducing loss of strength after soaking in water.

KEYWORDS : CLAYEY SAND, LIME, FLY ASH, HYDRAULIC CONDUCTIVITY

1. INTRODUCTION

Construction engineering using some problematic soil such as clayey sand (SC) is making steady progress in the vicinity of Bangkok, capital city of Thailand for many geotechnical constructions such as bottom liner in sanitary landfill. The problems are due to its undesirable properties such as low strength and high hydraulic conductivity. In order to proceed with constructions under such conditions, some techniques are needed to improve such poor properties of the soil. Recently, it has been found that appropriate chemical stabilization can improve undesirable characteristics of such soil. [1], [2].

Fly ash is one of the most potential waste from manufacturing industry which has been continuously crated due to population's increasing demand in energy uses, utility services and infrastructures in several cities. This study aimed to investigate the possibility to utilize such a waste as soil stabilizer. However, generally fly ash is considered as pozzolana which is not cemetitious itself. It has an ability to combine with Ca-rich materials such as lime, cement, etc. to form cementitious ones; e.g. calcium silicate hydrate (CSH), calcium aluminate hydrate (CAH), calcite ($CaCO_3$), etc. among soil particles due to the hydration and long-term pozzolanic reaction. [2], [3], [4]

This study aims to use fly ash mixed with small amount of lime to improve on such unfavorable properties of the soil as low strength and high hydraulic conductivity. The paper concentrates on content of stabilizing agents, compacting moisture content as well as curing period of samples. [1]

2. RESEARCH PROCEDURES

2.1 Materials

Unstabilized soil, clayey sand (SC) which is classified by the Unified Soil Classification System (USCS), was prepared in laboratory with a ratio of sand to clay of 88:12. A proportion represents the soil (SC) with the lowest clay content in this category according to the USCS. In order to get mixing consistency, clay was mechanically blended before mixing with sand passing No.10 sieve and retained on No.200 sieve.

Fly ash and lime were used as stabilizing agents to improve some engineering properties of SC which are unconfined compressive strength and hydraulic conductivity. A proportion of lime to fly ash was first determined based on standard compaction results of SC mixed with varying quantities of lime and fly ash as detailed in Figure 1. Compaction result giving the highest maximum dry density (MDD) was then selected as an optimum proportion of lime to fly ash. SC was then mixed with this proportion of lime to fly ash at stabilizer contents of 3, 6, and 10 percent.

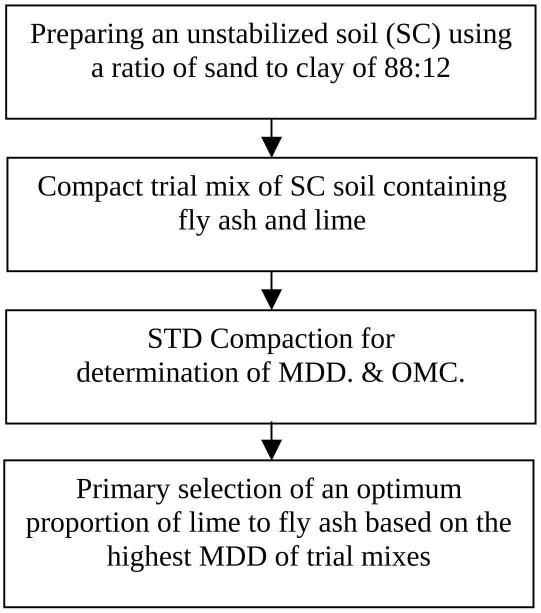

Figure 1 Primary study for determination of proportion of lime to fly ash

2.2 Sample preparation and Tests

Samples for engineering property tests were devided into 2 groups which are unconfined compression tests and hydraulic conductivity tests. Samples were prepared by compacting lime-fly ash mixed SC. Standard Proctor compaction was performed with varying water content from optimum moisture content (OMC) to two percent wet of optimum (OMC+2%). Preparation of hydraulic conductivity and unconfined compressive strength (UCS) samples were prepared using a mold of ∅4″x4.6″ (standard size) and ∅2″x4″, respectively. For UCS samples, compactive effort applied was equivalent to that of standard Proctor compaction (12,330 ft-lb/ft^3). After molding, the samples were sealed tightly in plastic bags to prevent loss of moisture content due to surface evaporation, then, they were cured in a temperature room. Hydraulic conductivity tests were performed by constant head method after curing time of 14 and 28 days. Strength test samples were cured for 7, 14, 28 and 90 days and divided into 2 groups (unsoaked and soaked samples) before performing by unconfined compression tests. An experimental program is illustrated in Figure 2.

3. EXPERIMENTAL RESULTS

3.1 Properties of Untreated Soil

Properties of untreated soil are shown in table 1. Soil used in this study was prepared in laboratory by mixing sand and clay fraction with a proportion of 88:12. According to the Unified Soil Classification System (USCS), The soil was classified as clayey sand (SC) having the lowest permissible clay fraction in this category.

Table 1 illustrates that SC is non-shrink due to oven drying for 24 hours. This indicates that SC would not be cracked when it dried. Also, results show that the soil is non-plastic (NP) indicating that there would be no swelling when wet. Based on physical properties, it is therefore recommended that this type of soil may be appropriate for many geotechnical constructions such as a bottom liner in sanitary landfill, etc.

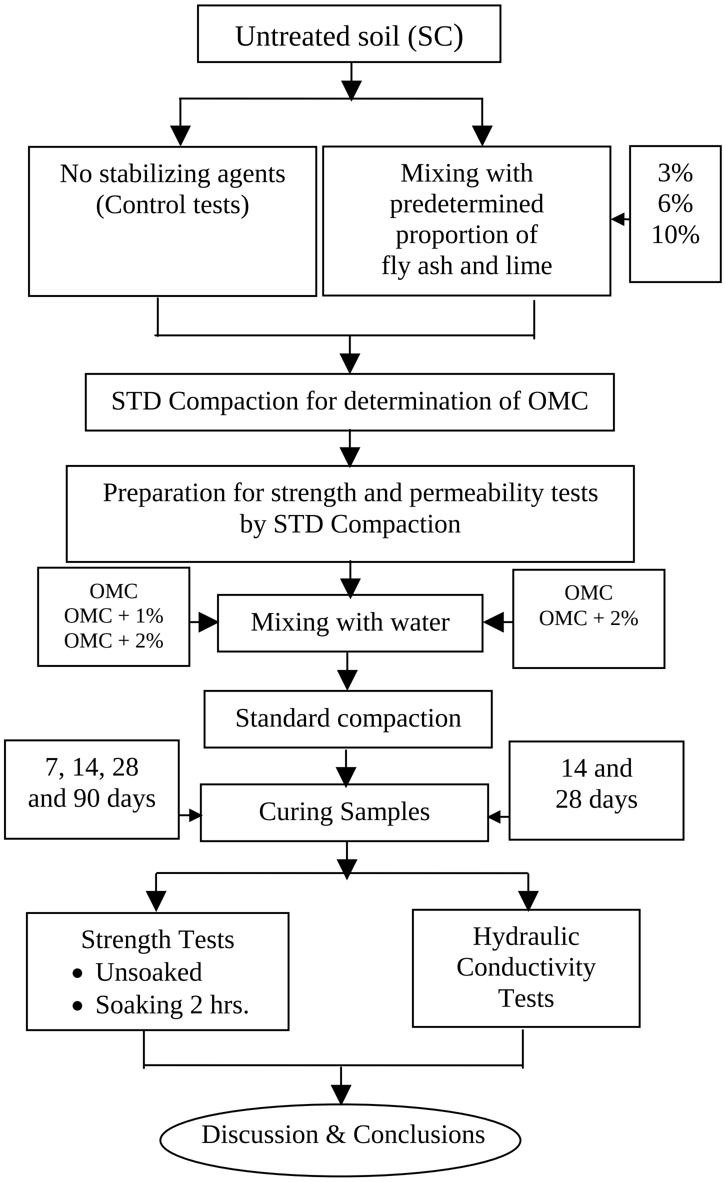

Figure 2 Experimental Program

However, as shown in Table 1, results of unconfined compressive strength tests show that SC has very low strength within a range of 0.10 - 0.24 kg/cm^2 in corresponding with moisture contents at OMC to OMC+2% while hydraulic conductivity of SC is a bit high within a range of 9.75x10^{-6} to 1.13x10^{-5} cm/sec. Therefore, some improvement techniques are needed to increase strength and reduce hydraulic conductivity of the soil.

This research proposes chemical stabilization using lime and fly ash as soil stabilization agents to improve such unfavorable properties of the soil. It is hypothetical that reactions among soil, lime, fly ash and water would perform among soil particles and produce some cementitious materials including CSH, CAH and calcite. They would help enhancement of higher strength and lower permeability of the soil.

Table 1 Properties of untreated soil

Properties of untreated soil	
Soil Classification (USCS)	Clayey sand (SC)
Coarse fraction (Sand, %)	88
Fine fraction (Clay, %)	12
Volumetric strain due to drying (Shrinkage potential)	Non - Shrink
Plasticity index (PI)	Non - Plastic (NP)
Maximum dry density (ton/m^3)	1.92
Optimum moisture content (%)	13.25
Hydraulic Conductivity (cm/sec)	9.75x10^{-6} to 1.13x10^{-5}
Unconfined Compressive Strength (kg/cm^2)	0.10 to 0.24 (Unsoaked Samples)

3.2 Determination of a mixed proportion of lime and fly ash

When SC was mixed with varied amount of lime to fly ash and was compacted with standard Proctor compaction, the results are shown in Table 2. The soil mixed with lime and fly ash were compacted in a standard mold (∅4″x4.6″). Based on compaction results, a proportion 1:20 of lime to fly ash was selected because of giving the highest maximum dry density (MDD). Selected proportion of lime to fly ash giving the highest MDD may be attributed to have good rearrangement of both soil particles and stabilizing agents. This formation causes better reactivities among soil, stabilizers and water to form cementitious materials and to improve some poor properties of the soil. SC was then mixed with this selected proportion at stabilizer contents of 3, 6 and 10 percent by dry weight.

3.3 Compaction Characteristics

As shown in Figure 3, similar relationship between compacted dry density and mixing moisture content can be observed when untreated SC were compacted using a standard mold (∅4″x4.6″) compared to those of compacted SC with a ∅2″x4″ mold. MDD and OMC were 1.91 tons/m^3 and 13.25 percent, and 1.84 tons/m^3 and 13 percent, respectively.

For compaction of SC mixed with 1:20 of lime to fly ash, results showed that similar relationship compared to those of untreated SC could also be found. The MDD was in a range of 1.95 to 2.04 tons/m^3 with conresponding OMC of 13 percent and at stabilizer contents of 3 to 10 percent.

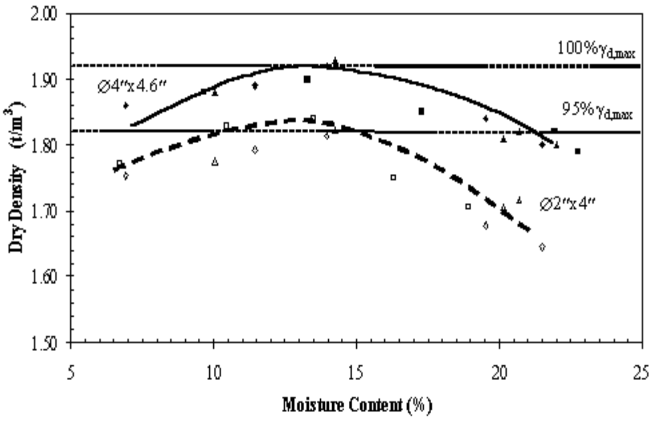

Figure 3 Relationship between dry density and moisture content of compacted SC in standard mold of ∅4″x4.6″ and cylindrical mold of ∅2″x4″

3.4 Hydraulic Conductivity of Stabilized Soil

Experimental results showed that hydraulic conductivity of soil mixed with fly ash and lime markedly decreases with an increase of stabilizer content while curing period has a little effect on reducing its hydraulic conductivity. In addtion, Figure 4 also shows that initial mixing moisture content obviously affect to hydraulic conductivity of the soil. Compaction at optimum moisture content (OMC) would give a lower permeabilty of the soil compared to that of compacted on 2 percent wet of optimum (OMC+2%). Results show that the average hydraulic conductivity of improved soil are about 2.56x10^{-6} to 6.68x10^{-6} cm/sec, 3.59x10^{-6} to 6.96x10^{-7} cm/sec and 9.27x10^{-8} to 5.67x10^{-7} cm/sec for amount of additives of 3, 6 and 10 percent, respectively. According to general required hydraulic conductivity for geotechnical engineering constructions such as a bottom liner in sanitary landfill (1x10^{-7} cm/sec), Experimental results suggested that use of 10 percent fly ash mixed with small amount of lime (1:20) and compacted at OMC would satisfy such requirement after curing for 28 days. Also, it can be predicted that use of more than 10 percent compacted at OMC may be possible to reduce hydraulic properties of the soil to meet other geotechnical construction purposes.

3.5 Unconfined Compressive Strength of Stabilized Soil

For unsoaked samples, strength untreated SC compacted at various moisture content of OMC to OMC+2% was in a range of 0.10 to 0.24 kg/cm^2 while soaked samples were slaked during soaking in waster for 2 hours for all cases, regardless initial mixing moisture content. In order to increase strength of the soil, chemical stabilization using fly ash and lime were proposed in this study.

As shown in Figures 5 to 7, experimental results illustrate that strength increases markedly with curing period and the stabilizers of both soaked and unsoaked samples. However, at 3 percent mix, strengths do not change markedly. This may be attributed that, at low stabiliztion, cementitious products might also be low, and they could not provide strength of the soil when compared to higher amount of stabilizers.

Rapid rate of gain in strength of improved SC was observed at early strength development for curing periods of 7, 14 and 28 days. For longer time of curing, results illustrated that strength of improved soils would be gained gradually at a curing time of 90 days.

Table 2 Maximum dry density and optimum moisture content of SC mixed with various proportions of lime and fly ash

Proportion of Lime : Fly ash(by dry weight)	MDD. (t/m^3)	OMC (%)
Untreated soil (SC)	1.91	13.5
1:40	2.06	7.0
1:30	2.09	7.6
1:20	2.11	9.0
2:20 (1:10)	2.07	8.6
4:20 (1:5)	2.01	9.8
10:20 (1:2)	1.98	9.0
0.5:20 (1:40)	2.02	12.0

Figures 5 to 7 show that strengths increase with increase of stabilizing agents. However, strengths do not change significantly for low stabilization content For the 3 percent mixes, result shows that maximum unsoaked unconfined compressive strength is only a range of 0.69 to 1.22 kg/cm^2 depending on their initial mixing moisture content. For use of 6-10 percent mixes, strengths change obviously perhaps due to hydration and pozzolanic reaction resulting in higher cementitious products inter-linked among soil particles. Stabilization at this level could achieve strength requirement of some geotechnical constructions such as a bottom liner in sanitary landfill ($2kg/cm^2$). For soaked strength, it was observed that there is loss in strength due to soaking the samples in water for all cases. However, it is obvious that loss in strength could be reduced when the soil was mixed with higher stabilizer contents and compacted at OMC. This may be attributed that, with higher amount of stabilizers, the microstructure of the soil is stronger and more stable. The results of loss in strength due to soaking in the water are illustrated in Figure 8.

3.6 Relationship among Loss in Strength, Hydraulic Conductivity and Stabilizer Contents

As discussed previously, soaking in water affected in decreasing strength of both untreated and improved soils. Relationship among loss in strength, hydraulic conductivity and amount of additives is illustrated in Figure 8.

After soaked, it may be attributed that the untreated SC-samples became slaked perhaps due to high hydraulic conductivity of the soil. Experimental results, as shown in Figure 8, illustrate that samples compacted at OMC has loss in strength less than that compacted on 2 percent wet of optimum. Relationships also reveal that increase of stabilizers causes higher degree of stabilization to produce cementitious products among soil particles resulting in stronger and less permeable microstructures. Therefore, increased amount of stabilizers significantly reduces the hydraulic conductivity resulting in reducing loss in strength after soaking in water.

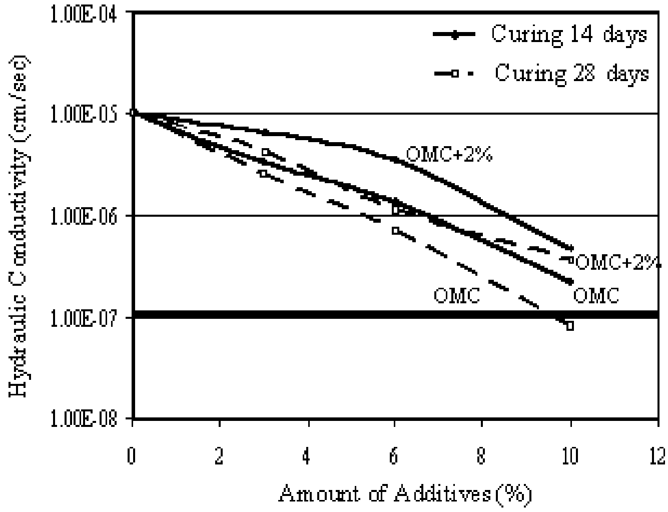

Figure 4 Relationship between hydraulic conductivity and amount of additives at mixing water content of 13 and 15 percent

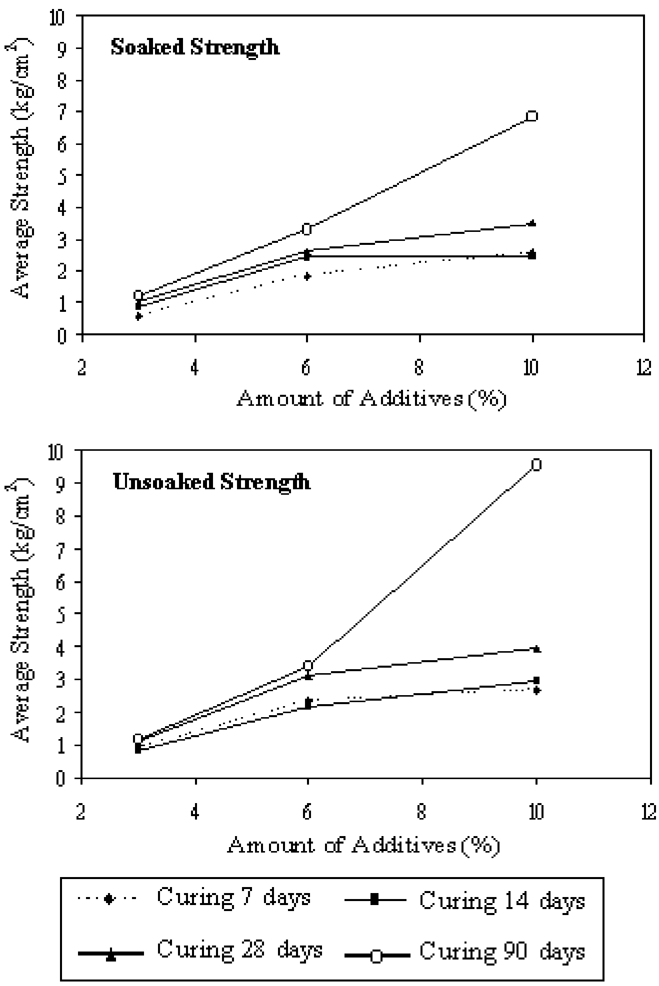

Figure 5 Relationship between average strength and amount of additives with various curing period at mixing moisture content of 13%

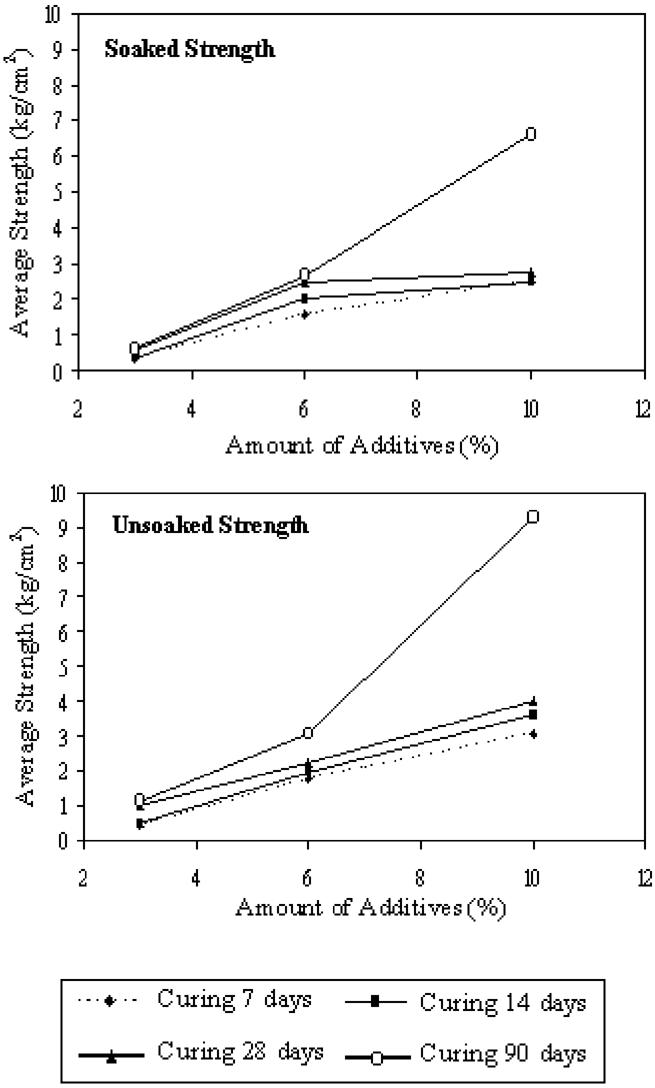

Figure 6 Relationship between average strength and amount of additives with various curing period at mixing moisture content of 14%

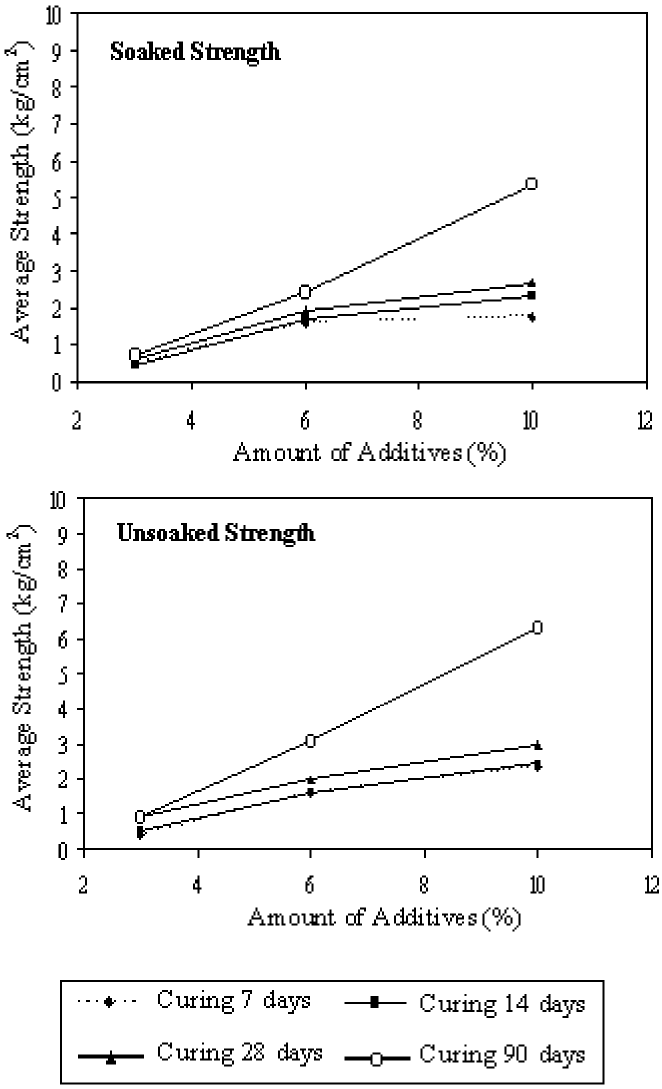

Figure 7 Relationship between average strength and amount of additives with various curing period at mixing moisture content of 15%

4. CONCLUSIONS

1. Based on compaction results, a proportion 1:20 of lime to fly ash was selected as a mixed proportion giving the highest MDD. In addition, similar relationship of compaction characteristics was also observed when different sizes of mold were used with equivalent compactive energy applied.

2. Hydraulic conductivity of improved SC markedly decreased with an increase of stabilizer content while curing period had a little effect to reduce their hydraulic conductivity. At the same content of stabilizers, results also show that soil compacted at OMC gave lower hydraulic conductivity when compared to that of compacted on 2 percent wet of optimum (OMC+2%).

3. Basically, for both soaked and unsoaked samples, strength significantly increases as stabilizer content increases. Rapid development of strength of improved SC was observed at early curing period perhaps due to hydration reaction among fly ash, lime and water. For long-term strength, it was attributed that pozzolanic reaction would perform to develop their strength continuously.

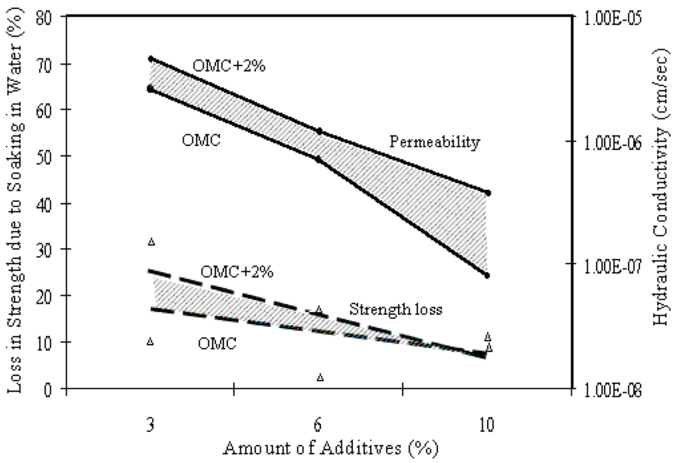

Figure 8 Relationship among strength loss-hydraulic conductivity and amount of additives at water content of 13 (OMC) and 15 (OMC+2%) percent at curing time of 28 days

4. It was then found that markedly loss in strength could be observed when saturated. Loss in strength due to soaking in water reduced with increase of stabilizer

content. This may be attribute that increased amount of stabilizers significantly reduces the hydraulic conductivity resulting in reducing loss in strength after soaking in water.

Therefore, based on experimental results, it is concluded that use of fly ash mixed with small amount of lime is possible to improve some engineering properties of SC including hydraulic conductivity as well as strength.

5. For further research, it is recommended that small amount of lime used how the reaction perform among sol particles. Basically, it is hypothesis that lime would enrich amount of calcium ions (Ca^{2+}) to react among soil particles. Consequently, exchangable ions; e.g. Al^{3+}, Si^{4+}, H^{+}, etc. would react with water, soil and fly ash to produce cementitious materials inter-linked among soil particles. Some technical investigation including scanning electron microscope (SEM), X-ray diffraction analysis (XRD) may be requested for advanced explainaion.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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