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Research Article

Stiffening of Clay by the Use of Paper Fly Ashes

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Abstract

To improve the stiffness and bearing capacity of natural soils, traditionally lime or cement is used. This research focuses on the performance of an industrial residual product paper fly ash (generally treated as waste) as an alternative binder for soil stabilization. The present report summarizes the research carried out at the Ghent University. The research focused on the stabilization of kaolinite and bentonite clay. The experimental research consisted on monitoring the evolution of stiffening by time of a number of soil samples mixed with paper fly ashes. To this end, a non-destructive test was implemented to evaluate the small-strain stiffness of each specimen at different stages of curing. Kaolinite clay was chosen as reference clay material for stabilization. A commercial processed kaolin Rotoclay HB (Goonvean, St. Austell, UK) was used in this investigation. Kaolinite shows relatively low plasticity levels comparable to commonly found fine-grained soils. The non-destructive free resonant column test was used to evaluate the small-strain Young's modulus (E_0) of the soil specimens after stabilization with paper fly ash. The limited scatter of data suggests good repeatability and reliability. The first conclusions with regard to the application for soil stabilization are discussed.

Keywords: Soil Improvement; Paper Fly Ashes; Lime; Kaolinite; Bentonite; Free Resonant Column Test

Introduction

A limited bearing capacity of the subsurface may be the result of a bad quality and/or an insufficient compaction of the natural soil. For sandy soils the technique of improvement is in many cases compaction. For fine graded soils, and in case compaction doesn't result in a higher bearing capacity, the soil can be mixed with stabilizing material. Traditionally lime or cement is used. Åhnberg [1] made an evaluation of the effect of different binders on the mechanical characteristics of clayey soils. In this research no direct relation could be made between the types of binders and the results of the modified soil characteristics. The authors confirmed that the change in strength of the soil depends on a number of factors. Previous research at the Ghent University proved that mixing paper fly ash improved the bearing capacity. Recently more research was carried out to confirm these results. Paper fly ash, with a significant lime content, results from the process of paper production. It is a residual product after incineration of paper and wood. The working effect of paper fly ashes as a binder are still insufficiently studied. The paper fly ashes discussed in this article have a large amount of free lime (9%). When paper fly ashes are mixed with clay two reactions occur [2]. In the first reaction there is an exchange of the cations in the soil and a flocculation immediately after mixing the binder with the clay. The second reaction is the pozzolanic reaction. This is a very slow reaction between CaO, H_2O, SiO_2 and Al_2O_3. In a previous study, made by Servaco [3] a lot of test results on the composition of paper fly ash were examined. In a later research Libbrecht [4] proposed 5% as an optimum percentage for mixing with silt. For this content the maximum CBR-value was reached. Out of a detailed research on the characteristics of paper fly ashes, made by the BAS Research and Technology Center [5], it could be concluded that paper fly ash contains a large percentage (13 %) of the mineral belite. Belite is also found in Portland cement and ensures the strength development over time. In 2018 [6] a first research on the influence of paper fly ashes on the stability of clay was made.

Materials and Methods

Kaolin clay was chosen as reference clay material for stabilization. A commercial processed kaolin Rotoclay HB (Goonvean, St. Austell, UK) was used in this investigation. Kaolinite shows relatively low plasticity levels, comparable to commonly found fine-grained soils. Table 1 summarizes some properties of this material. A freshly produced batch of paper fly ashes was provided by ATA International (commercial name Ecolime). The chemical composition is given in Table 1.

Table 1: properties of Ecolime.

Component	Percentage
SiO_2	22.25
Al_2O	12.34
Fe_2O_3	0.95
CaO	53.15
MgO	2.71
K2O	0.52
Remaining	0.78

The stiffening of Kaolin clay specimens stabilized with Ecolime at 6% dosage was monitored for a curing period of almost 200 days. The dosage of Ecolime was set based on the Eades & Grim test which determines the saturation dosage [7]. The test consists in measuring the pH of different soil-additive mixtures at different dosages and comparing them to the pH of the additive saturated solution (reference pH). The results of this test are illustrated in Figure 1. The upper boundary of Ecolime dosage for Kaolin clay treatment is about 6% in dry weight. Higher amounts of additive will produce no additional improvement. Therefore, it was decided to prepare samples at a dosage of 6%. Kaolin clay and Ecolime (at a dosage of 6%) were initially dry mixed in a dough mixer to ensure homogeneous distribution of the additive. Then, water was added to bring the mixture close to the optimum water content for standard Proctor compaction (w = 27%). Then, a number of specimens were compacted and cylindrical samples with a diameter of 50 mm and height of 100 mm were obtained through cutting and trimming. All specimens were allowed to cure in a humid environment at constant temperature of about 20^0C.

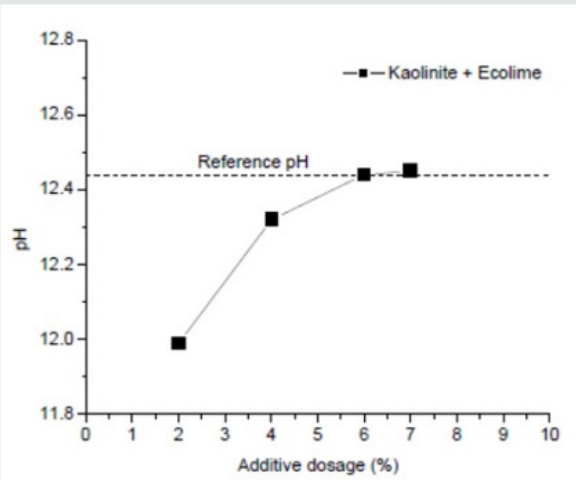

Figure 1: Evaluation of maximum dosage for stabilization.

The non-destructive free-free resonant column test was implemented here to evaluate the small-strain Young's modulus (E_0) of the soil specimens stabilized with Ecolime. The testing setup is illustrated in Figure 2. It consists of an accelerometer put in contact with the soil specimen at one end. At the other end, the soil specimen is impacted with a light hammer. The sample is laid horizontally on soft foam. The impact of the hammer generates waves of a broad range of frequencies. However, only the waves at a frequency similar to the fundamental frequency of the specimen will be amplified on its way to the accelerometer. Then, the signal captured with the accelerometer can be analyzed to evaluate the fundamental frequency of vibration of the specimen. Finally, this frequency can be correlated to the stiffness E_0 through elasticity theory based formulations. The stiffening of kaolinite and kaolinite-bentonite clay specimens stabilized with Ecolime at 6% dosage was monitored for a curing period of almost 200 days. The samples KEx refer to samples of kaolinite clay stabilized with 6% of Ecolime. The Figure 4 shows the comparison between the increase of stiffness between samples of kaolinite clay (KEx) and samples of a mixture of kaolinite clay (70%) (KEx) and montmorillonite (bentonite) clay (30%) (KBEx).

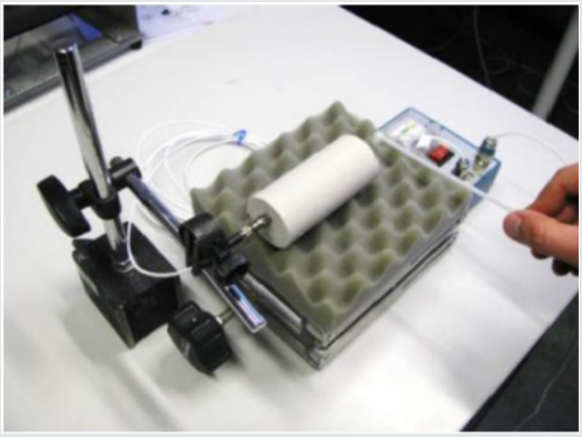

Figure 2: Free-free resonant column testing setup.

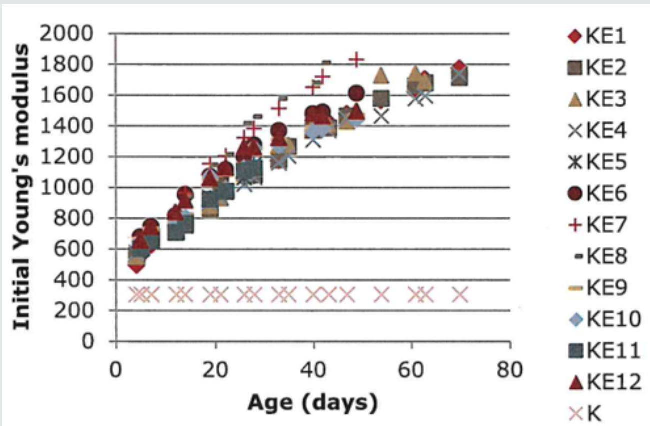

Figure 3: Small-strain Young's modulus evolution with time for Kaolinite and Kaolinite stabilized with Ecolime.

Results and Discussion

The results are illustrated in Figures 3 & 4. Figure 3 shows E_0-measurements on 12 specimens with the same dosage of 6% and natural kaolinite (K). The limited scatter of data suggests good repeatability and reliability. Moreover, the non-destructive technique produced a well-defined and continuous E_0 increasing pattern. E_0 was observed to increase almost linearly with time up to the 60^{th} day of curing approximately. After that, the stiffness increasing rate significantly decreased. The evolution of E_0 reflects the evolution of interparticle cementation in the clay fabric due to the addition of paper fly ash. However, the beneficial impact of the additive may also be affected by the composition and properties of the natural soil and local groundwater. In Figure 4 a difference can be seen between the kaolinite and the kaolinite-bentonite samples. The kaolinite-bentonite samples have a bigger initial E_0-modulus than the samples made from pure kaolinite. The different properties of the various families of clay minerals can be explained partly by the different levels of activity on the surface of the clay particle. Expansive clay minerals such as bentonite exhibit a high cation exchange capacity, whereas non-expansive clay minerals like kaolinite have a relative low cation exchange capacity.

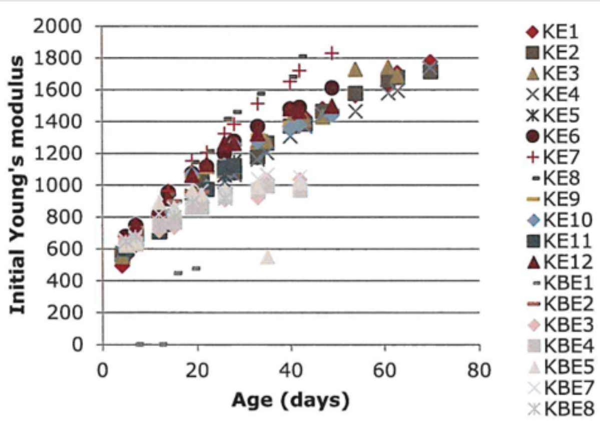

Figure 4: Small strain Young's modulus evolution with time for kaolinite clay and bentonite-clay samples stabilized with Ecolime.

Conclusion

The laboratory tests, in particular the free resonant column tests, indicate that a stabilization with paper fly ashes or with lime have similar properties. For soils with a high amount of kaolinite, paper fly ash has the same stabilization effect as lime. >For soils with a high amount of bentonite, lime is a better binder. After 28 days the effect of stabilization with paper fly ash is comparable with the stabilization with lime. Although the results are very promising, it remains important to study the chemical reactions in the sample with the X-ray diffraction method. The beneficial impact of the additive may also be affected by the composition and properties of the natural soil and local groundwater. More research is needed to confirm these results.

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