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Evaluation of kaolin slurry properties treated with cement

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ABSTRACT

Kaolin clay has features high compressibility and also very low strength. Stabilization methods are normally used to improve the mechanical and chemical characteristics of cohesive soil. This study has examined the kaolin properties treated with cement using the unconfined compression strength (UCS) test, direct shear test, and constant rate of strain (CRS) consolidation test. The strength characteristics of kaolin mixed with cement have been investigated using the UCS test and direct shear test. Then the consolidation behaviour of this treated soil was evaluated by performing the constant rate of strain (CRS) consolidation test. The selected cement content range was 5%, 7.5%, 10%, 12.5% and 15%. Water content was used at twice the liquid limit of kaolin in order to produce a homogeneous and workable sample to be placed inside a curing mould. All the samples were cured for 12 days. Based on the UCS results, it was found that the increment of the cement content led to an increase in unconfined shear strength and elasticity modulus of the improved soil and it also caused the water content to decrease after curing. Although the internal friction angle is not considered in saturated clay soils, this experimental result shows that it can be improved by raising the amount of cement. The results of the CRS test indicated a decrease in the slope of the void ratio curve with an increase in cement content. In addition, the variations of void ratio are augmented by the increase of cement content in a constant effective stress.

1. Introduction

Kaolin clay has features high compressibility and also very low strength. In order to improve the mechanical characteristics of soil, a stabilization method is usually employed by mixing the cohesive soil with stabilizing agents [1–4]. According to previous research in the soil stabilizing field, an increase in the amount of stabilizing agent leads to an increase in the compressive strength, based on the attributes of the soil and binder. In addition, they referred to cement as the strongest binder for stabilizing soft soil [5–7]. Within Asian countries the employment of cement is more popular than that of lime, not only because it is plentiful and costs less, but also because cement works more effectively than lime [8]. A cement composite material is produced due to interaction between clay and a stabilizing agent after the mixing process. These interactions increase the soil strength, which leads to reducing the settlement and improving the bearing capacity [1]. Due to the faster cement hydration process than for lime, the Coastal Development Institute of Technology (2002) and Chew et al. [4] reported that cement creates more strength during the initial period than lime with the same quantities. Cement binders are the most universal stabilizing agents that could be used for different types of soil conditions [6,9,10]. The two main reactions that produce cementitious materials occur during soil cement or lime treatment curing, namely hydration reaction and pozzolanic reaction [4,11–13]. For soil cement, the reaction of the mineral with water in the soil produces cement hydration and calcium hydroxide, while for soil-lime treatment, lime hydration and calcium silicate and calcium aluminate are produced

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[14,15]. The calcium hydroxide (soil-cement) and calcium silicate and calcium aluminate (soil-lime) then contribute to the pozzolanic reaction. The hydration process and exchange action reduce the soil water content and thus the physical properties will be improved contributing to an increase in soil strength; however, the increase of the shear strength depends mainly on the pozzolanic reaction [16]. From the reaction, new pozzolanic products are developed that bind together the clay particles to produce a stronger soil matrix [13]. The process is completed within several weeks and the majority of the strength increase occurs during this period [15]. It has been documented that the degree of improvement is related to the amount of binder added, binder type and curing time [4,10,15,17–19]. The strength increases almost linearly with an increase in the amount of binder [11,12]. For instance, Uddin et al. [20] found that by adding 10% of cement to soft Bangkok clay, the unconfined compression strength increased by up to 10 times. The natural moisture content of the soil used ranged from 76% to 84%. It is evident that the strength and stiffness increase at very low cement content. Ductile behaviour was observed at low cement contents below 10%, with no obvious peak stress. At higher cement contents, the treated soil behaved as a brittle material with very high strength and at a strain up to 2% [20]. Terashi et al. [21] observed that the axial strain at failure for treated soil with Portland cement decreased with increasing unconfined compressive strength. In this particular research the fundamental characteristics of kaolin clay treated with cement are examined by laboratory investigations. These results can be used for the design of a soil stabilization method and deep soil mixing.

2. Material and methods

The tests were run on kaolin clays using samples obtained from commercial powdered kaolin (L2B20) supplied by Kaolin (Malaysia) Sdn. Bhd. Their index characteristic values are summarized in Table 1. As kaolin powder has more than 80% of particles classified as clay particles (under 2 μm size) of specific gravity, Gs, 2.60 was used. Selection of the stabilized material and determination of the exact amount to be used as an additive were critical as they directly affect the structural performances of the ground improvement method. A soil-cement mixture was prepared using a mix of ordinary portland cement (OPC) and kaolin. OPC powder with a specific gravity of 3.08–3.18 was purchased from Lafarge Malaysia Berhad. The mixture proportions depended on the amount of cement and water added to the kaolin needed to gain a certain strength of mixture, which was ascertained using several trial mix designs. The typical mineralogical composition of OPC used in this study is given in Table 2. All the specimens were prepared by mixing the kaolin and the OPC powder with de-aired water. Oven-dried kaolin powder and OPC were poured into the mixing bowl of a food mixer at a controlled room temperature of 23 °C. The food mixer initially ran at a low speed of 50 revolutions per minute to avoid spillage for 1 min. The mixer was stopped after the colour of the powder changed uniformly. This technique was employed to ensure that the powder was well mixed. The water was then added, with the amount being sufficient to make sure that the sample could be homogeneously mixed and would have a high enough degree of workability to be placed inside a mould. This amount was twice the liquid limit (LL) of kaolin suggested by Rashid et al. [7] and Rashid [22]. The mixer was then started for 1 min at the same low speed to avoid spillage. It was then stopped and the material was scraped off the paddle and sides of the bowl before mixing was resumed for another 10 min. This procedure was conducted to achieve a homogeneous mix as suggested by the Japanese Geotechnical Society Standard [23]. The samples inside the mould were cured for 12 days at a controlled room temperature of 23 °C and relative humidity of 95%.

Table 1
Characteristics of Kaolin Clay.

Properties	Characteristics values
Liquid limited	54
Plastic limited	30
Plasticity index	24
Particle density (g/cm^3) kaolin	2.60
Particle density (g/cm^3) Kaolin +5% cement	2.61
Particle density (g/cm^3) Kaolin +7.5% cement	2.63
Particle density (g/cm^3) Kaolin +10% cement	2.64
Particle density (g/cm^3) Kaolin +12.5% cement	2.66
Particle density (g/cm^3) Kaolin +15% cement	2.67

3. Results and discussion

The influence of kaolin treated with different percentages of cement has been investigated. In order to obtain the stiffness parameters of cement-stabilized kaolin clay, the UCS test and direct shear test were used with British standard BS 1377: Part7:1990. Also, the CRS test was employed to examine the settlement behaviour.

3.1. Unconfined compressive strength

As was mentioned above, each specimen for the UCS test was made and cured according to stabilized soil specimens without compaction (JGS 0821). Then the mixture was poured in 3 layers into PVC tubes with a 38 mm internal diameter by 78 mm height. Air bubbles were removed by lightly tapping the mould against a rigid plate after pouring each layer of slurry. The above operations were terminated once air bubbles were no longer observed on the soil surface. A palette knife was used to trim the top of the soil before a cap was put on the top of the tube and sealed with tape.

The results of UCS tests of cured samples at 12 days are presented in Figs. 1–6 and Table 3. In the unconfined compression strength, q_u improved with increasing cement content, which agrees with the results of earlier investigations. The increase in strength with cement content is attributed mainly to the cement hydration that leads to the dissociation of calcium ions that eventually react with