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Tropical residual soil stabilization: A powder form material for increasing soil strength

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HIGHLIGHTS

- Laterite soil stabilized using a calcium-based additive prepared from biomass silica.
- Stabilized laterite exhibited significant strength gain, even with short curing times.
- Strength gain attributed to formation of calcium aluminate hydrate cementing agents.
- Selected stabilizer appears effective for field treatment of tropical laterite soil.

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ABSTRACT

Stabilization of problematic soils for earthwork applications can be performed using a variety of chemical additives, with lime, cement, or fly ash all being traditionally employed for this purpose. More recently, various new calcium-based additives have been actively marketed by a number of companies for soil stabilization applications. The stabilizing mechanisms of these commercially available products are not fully understood, and their proprietary chemical composition makes it difficult to predict their effectiveness. The current study examines the effectiveness of SH-85, a new calcium-based powder additive which is prepared from biomass silica, for stabilization of a tropical residual laterite soil. At the macro-level, changes in soil strength due to additive stabilization were assessed using a series of unconfined compression strength (UCS) tests. The underlying mechanisms that contributed to the stabilization process were explored using spectroscopic and microscopic techniques, including X-ray diffractometry (XRD), energy-dispersive X-ray spectrometry (EDAX), field emission scanning electron microscopy (FESEM), and Fourier transform infrared spectroscopy (FTIR). The UCS test results indicated that the addition of SH-85 powder had a significant stabilizing effect on the laterite soil, with the UCS values increasing fivefold after a 7-day curing period. At the micro-level, addition of SH-85 had a weathering effect on the clay minerals, changing the peak intensities of the observed minerals in the XRD spectrums as the stabilized soil was cured. A significant change in the soil fabric was also observed with curing time in the FESEM tests, with additive stabilization yielding a less porous and denser soil fabric, and changes in the surface appearance of treated clay particles. This research study confirms the potential of SH-85 as an alternative to traditional stabilizers for construction involving tropical residual soils.

1. Introduction

For transportation earthwork applications in geotechnical engineering, the availability of high quality soil for construction is often limited in many parts of the world [1,2]. More often than not, engineers are forced to find alternatives to the use of locally available soils in order to meet soil strength, compressibility, or permeability requirements that are stipulated by a given project. For most applications, engineers are generally left with two alternatives: (1) excavate and replace problematic soils with imported backfill materials, generally an expensive proposition with significant logistical and sustainability problems, or (2) stabilize or otherwise improve locally available soils to achieve the required material

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properties [3–7]. For the second approach, there are a variety of options available to chemically stabilize poor quality soils, using either traditional or non-traditional additives [8–15].

In tropical regions, the weathering process for soil and rock is typically much more rapid than what occurs in more temperate climates, with speedy disintegration of feldspars and ferromagnesian raw materials, displacement of silica and bases (Na_2O, K_2O, MgO), and absorption of aluminum and iron oxides being common [16]. This residual soil formation process, which includes leakage of silica and decomposition of iron and aluminum oxides, is commonly referred to as *laterization* [17]. Tropical regions are ideal for formation of laterite residual soils, as warm temperatures, significant quantities of rainfall, and the presence of deeper geologic deposits that allow for subsurface drainage are common [18,19]. Consequently, substantial layers of lateritic residual soil are often formed, which typically have significant amounts of aluminum, iron, and kaolinite clays [16]. The existence of iron oxides makes the color of laterite soils red (from light to bright red), with brown shades also being common [20,21]. The presence of significant quantities of fine-grained soil within most laterite deposits can be attributed to the significant soil weathering that has occurred. The fine-grained nature of laterite soil deposits causes this type of soil to be problematic from an engineering point of view, with natural soils sometimes needing stabilization [22,23].

Traditional chemical stabilizers such as cement, lime, fly ash, and bituminous materials are widely studied and their essential stabilization mechanisms are generally well-understood [24–33]. The list of non-traditional chemical additives is much broader, including enzymes, liquid polymers, resins, acids, silicates, ions and lignin derivatives [34–39]. The chemical nature of these non-traditional additives is quite varied relative to traditional chemical stabilizers, and the manner in which they react with soil during the stabilization process is consequently also quite different for each type of stabilizer that is used [40–42]. Relative to traditional stabilizers, only limited information exists in the technical literature about the underlying stabilization mechanisms that occur when different non-traditional additives are used to stabilize different types of natural soils [43,44].

In recent years, various types of non-traditional additives have been actively marketed by different companies for stabilization of fine-grained soils [45,46]. Due to their proprietary chemical composition, the stabilizing mechanism of these products is not fully understood and hence, it is difficult to predict their performance. Some previous studies have indicated that various non-traditional additives can be used to increase the strength properties of certain natural soils [47–52]. Other studies have effectively used X-ray diffractometry (XRD), energy-dispersive X-ray spectrometry (EDAX), field emission scanning electron microscopy (FESEM), and Fourier transform infrared spectroscopy (FTIR) tests to examine the mineralogical composition and micro-structure of soils [53–55]. These techniques have also been used to study the micro-structure of soils that have been stabilized using different types of non-traditional additives [4,56–58].

The objective of the current study is to assess the capabilities of SH-85, a commercially available calcium-based powder form additive prepared from biomass silica, for stabilization of a tropical residual laterite soil from Malaysia. To accomplish this task, changes in the macro- and micro-structural properties of a laterite soil stabilized with SH-85 were explored over various curing periods. A series of unconfined compression strength (UCS) tests were performed to examine the physical changes in soil strength that were induced by the additive stabilization process over time. In parallel, changes in the soil micro-structure over time were investigated using a series of spectroscopic and microscopic tests, including XRD, EDAX, FESEM, and FTIR tests. The results from these tests are useful for understanding the effectiveness of tropical residual soil stabilization using SH-85, and for assessing the underlying mechanisms through which the laterite soil was stabilized.

2. Materials and experimental program

2.1. Materials

For this study, soil testing was performed on a residual laterite soil that is common in tropical areas. Representative block samples of a reddish laterite clay rich in iron oxides were obtained from a depth of 2 to 3 m below the ground surface, by performing excavations in a hillside located at the Skudai campus of Universiti Teknologi Malaysia (UTM). The natural soil was air-dried under laboratory conditions, after which pebbles and plant roots were removed. Grain size analyses of the resulting soil indicated that a significant quantity of fine-grained particles are present, as shown in Fig. 1. Table 1 presents the physical properties of this soil, which were determined using a variety of traditional soil characterization tests. Additional characterization test results for this soil (including more details from compaction testing) are available in Marto et al. [8]. The color of this clayey soil is reddish due to the high amount of iron oxides that are present.

The stabilizing additive that was utilized, which goes by the commercial name SH-85, is a calcium-based powder additive which is prepared from biomass silica. The selected additive was sold by the Probase factory located in the Johor province of Malaysia; the exact chemical composition of this stabilizer has not been released by the manufacturer, since it is a commercially registered brand. Table 2 shows the general chemical properties of this additive and the selected laterite soil, which were determined using EDAX testing; the associated pH (L/S = 2.5) for this additive is 12.65. As shown in Table 2, the dominant compounds in SH-85 are calcium oxide (68.21%), silica (9.25%), alumina (12.30%), and carbon dioxide (10.24%).

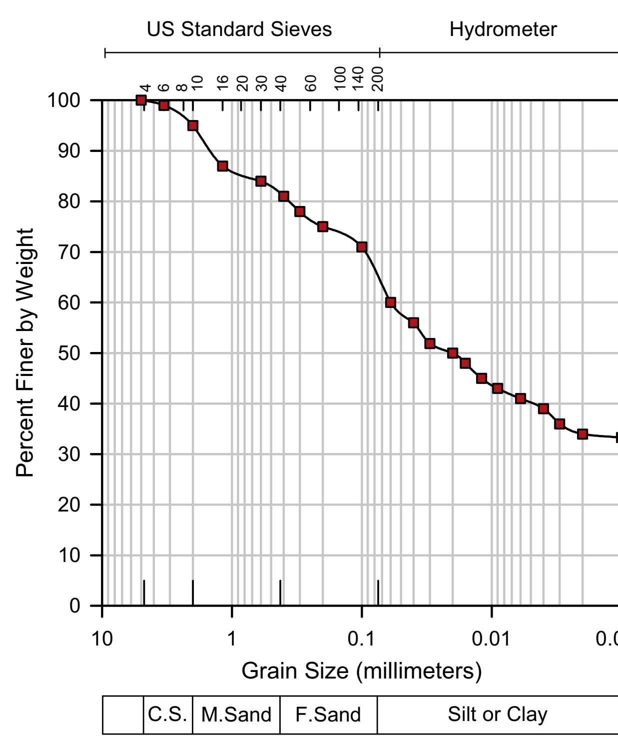

Fig. 1. Particle size distribution of the tested laterite soil.