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Three point bending flexural strength of cement treated tropical marine soil reinforced by lime treated natural fiber

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ABSTRACT

Marine soil in the Selangor State of Malaysia was characterized with respect to its engineering properties as pavement layer in road constructions. Samples were collected from North Klang area in Selangor, Malaysia and subjected to physico-chemical, mineralogical and geotechnical analyses. Quick lime or calcium oxide (CaO) treated coconut fibers were introduced to soil cement mixture to enhance the flexural strength of tropical marine soil. Three point bending tests were carried out on treated samples after 7, 14 and 28 days respectively. The tests results showed improvements in the flexural performance of the mixture as it could be seen by the increase in the flexural strength, Young's modulus and the toughness index especially when the treated fibers were incorporated into the mixture. It was found that, the bond strength and interaction between treated fibers and soil was the dominant mechanism controlling the reinforcement benefit. It can be concluded that, the application of the CaO treated coconut fiber reinforced cement treated marine clay from Peninsular Malaysia is useful both in strength and ductility as pavement layer in road constructions.

1. Introduction

The prospects of infrastructural projects have expeditiously expanded around the globe in recent times. Huge demand for usable land is one of the consequences to execute such developmental projects such as road construction. As a result of high demand of land, the full utilization of any available land is important; regardless the condition of the land such as the unsuitability of the land for construction purposes due to its poor engineering properties (e.g. high compressibility, low shear strength, uneven distribution of moisture and cracks development, among others). As such, engineers have faced considerable challenges in the constructions of various coastal structures. Large deposits of weak tropical marine clays are encountered throughout the peninsular Malaysia. They are found in Johor, Malacca, Klang, Penang and Alor Star. The properties of this marine soil depend on its initial conditions. A comprehensive review of literature indicates that, extensive amount of work related to the determination of the engineering behavior of marine soil has been carried out worldwide for the past five decades. The properties of marine soil vary significantly for moist and dry soils. In tropical area, the soil has higher proportion of organic matters that acts as cementing agent [1]. Previous works on the use of marine clays as a non-conventional construction material have been reported. The treatment of the unconfined marine clay by adding significant amount of cement has improved its compressive strength [2]. Significant research on strength and stiffness characteristics was performed [3,4]. Also the application of marine clay with palm clinker as an artificial aggregate has been reported by Chan and Robani [5]. Different materials and construction techniques are required to provide civil engineers alternatives to traditional road construction practices. Alternatives to traditional construction materials including stabilization of local materials and utilization of asphalt/Portland cement concrete pavement systems are expensive and cost prohibitive for low volume roads [6]. As such, various construction techniques have been employed for road construction purposes. Subgrade soil functions principally to transfer applied loads from pavement to the layer beneath, therefore it should have a sufficient load carrying capacity. Cement treatment in soil improves strength as well as stiffness, although it imparts brittleness in soil. All structural layers in pavement are subjected to tensile (flexural) stresses. As a result, zone tensile stresses develop in earth structures such as embankments, dams and multilayer pavements due to flexure. Tensile strength is one of the most important design parameters to consider when reinforcement materials are

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embedded in the soil [7]. Recently, locally available natural fibers such as coconut fibers are used as soil reinforcement material due to their availability, low cost and environmentally friendly nature. Despite these many advantages of coconut fiber as soil reinforcement [8–11], some modifications or pre-treatment are always useful to improve the performance of coconut fibers in soil matrix [12–16]. Alkaline treatment is one such method to improve mechanical properties of natural fiber used as soil reinforcement in subgrade soils. In this method, a strong sodium hydroxide (NaOH) is used to remove lignin, hemicellulose and other alkali soluble compounds from the surface of the fibers in order to increase the number of reactive hydroxyl groups on the fiber surface to enhance chemical bonding [16–18]. Study by Ramesh et al. [50] mentioned that kerosene, bitumen and varnish were used to coat the coconut fibers in order to modify the surface of the fibers. This study is inspired by the idea of treating coconut fiber by saturating it with lime. In the current study, slaked lime is used to improve the interfacial bond characteristic of coconut fiber reinforced cemented soil. Slaking is a process of converting quick lime to hydrated lime by reacting with water which leads to a better use of lime in pavement stabilization work. Silva et al. [51] indicated that lime treatment was efficient in preserving the cellulose structure of coconut fiber initially. Cellulose is the main structural constituent of plant fibers, as such tensile strengths and Young's modulus increases with increase cellulose content in plant fibers. This study aims therefore to investigate the flexural behavior of the cement stabilized tropical marine clay soil which is reinforced with untreated and treated coconut fibers. Also, the effect of fibers on the flexural characteristics of the reinforced treated cement stabilized soil was analyzed.

2. Material and methods

2.1. Raw material

2.1.1. The clays

Tropical marine clay used in the study was collected from North Klang area in Selangor, Malaysia. The location of the sampling point of the marine clay at Port Klang, Malaysia is shown in Fig. 1. Clay samples were collected along seashore in Selangor at the depth of 5 m. A total of three locations were selected for sampling using trial pit method, the soil was dark grey in colour containing some organic features like decomposed decaying organic matters. Samples were bagged, labelled and transported to the laboratory for studies.

2.1.2. Cement

The cement used in the study was ordinary Portland cement Type 1 obtained from local cement factory. Table 1 summarizes the chemical and physical properties of the cement.

2.1.3. Coconut fibers

Coconut fibers used in this investigation were brown fibers obtained from a factory in Batu Pahat, South of Malaysia. Fibers of length 15 mm and 0.2–0.3 mm in diameter were used in the study (Fig. 2). In addition, lime was used as treatment materials of coconut fibers. The chemical composition of quick lime (CaO) used in this study is given in Table 2.

The chemical and physical properties of coconut fibers are given in Table 3.

The large discrepancies among values reported for tensile strength of coconut fibers generally present variable and irregular cross-sections were correlated with their tensile behavior. The differences of cellulose content of the natural fibers were also affected to the fiber resistance for each single fiber [11].

2.2. Specimen preparation

2.2.1. Pre-treatment of fiber by lime

The coconut fiber was pre-treated by slaked lime with a concentration of 0.5 M of CaO in 500 ml aqueous suspension for 24 h (Fig. 3). The product was saturated in a beaker covered with aluminium foil and kept for 24 h. After 24 h, the treated fiber was washed and kept at room temperature for 4 days prior casting.

2.2.2. Standard proctor compaction

The standard proctor compaction test according to ASTM D698-70 was conducted to determine the initial compaction characteristics of the soil specimen alone, cement and fiber reinforced soil. After the optimum mix proportion was determined, the specimens were then prepared in the form of a beam. For plain soil-cement, all mixtures (cement, clay and water) were mixed in a mixer for 5 min. For fiber inclusion soil cement, untreated and treated coconut fibers were added into the fresh soil cement and mixing was continued for another 5 min until the fibers were distributed thoroughly. Details on mix proportion and number of specimens are given in Table 4.

2.2.3. Casting of beams

In order to evaluate flexural characteristics of fine-grained soils subjected to bending conditions, a flexural beam test setup was developed with beam dimensions of 250 mm in length, 50 mm in width, and 50 mm in depth, respectively (Fig. 4). Several investigators have maintained a same ratio of length l to breadth b and length l to depth d in the range of 4–5 [19–23]. Compaction was carried out using a rammer of 50 mm in diameter and 2.5kg in weight, falling freely from a height of 300 mm above the surface. This standard compaction advocated the beams being constructed in four layers of 25 mm thickness, each layer imparted with 100 evenly distributed blows. The specimens were removed after 24 h and wrapped with plastic sheets for 7, 14 and 28 days prior the test date (Fig. 5). Out of the many beams tested, the behavior of 36 selected samples was considered in this paper including both unreinforced and reinforced clay beams.

2.2.4. Flexural strength test

The three point bending test (flexural) was conducted on soil beam specimens. The ASTM D1609 was used as a reference in order to determine a testing procedure. A flexural beam test setup was developed with clay beam dimensions having 250 mm in length, 50 mm in width, and 50 mm in depth were vertically loaded at the middle on two simple supports until failure. The loading rate of 0.1 mm/min at room temperature and in normal humidity conditions was subjected to the specimens. The specimen was placed onto two supports with a 130 mm span length. The flexural stress for square section of the outer layer of the specimen was calculated. The deflection measurement in three point tests is measured using the machine's crosshead position sensor (a digital encoder). Results from the load-deflection curves are used for calculating value such as flexural strength test using this equation.

$$FS = \frac{3PL}{2BH^2} \tag{1}$$

where FS is flexural strength or modulus of rupture (MPa), P is the breaking load (N), L is the span of the simple supports (mm), B is the width of the specimen (mm) and H is the thickness of the specimen (mm).

Young's modulus can be obtained from:

$$E = \frac{PL^3}{4\Delta BH^3} \tag{2}$$

where E is modulus elasticity (MPa), P is the breaking load (N), L is the span of the simple supports (mm), B is the width of the specimen (mm), H is the thickness of the specimen (mm) and Δ is deflection of beam (mm).

Evaluation of toughness indices of cemented soil was referred to ASTMC1018. The evaluation method based on ASTM C1018 is a frequently-used approach to determine flexural toughness of fiber reinforced concrete. In this evaluation method, 4 flexural toughness