



Utilization of sodium bentonite to maximize the filler and pozzolanic effects of stabilized peat

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ARTICLE INFO

Article history:

Received 12 June 2012

Received in revised form 3 October 2012

Accepted 13 October 2012

Available online 8 November 2012

Keywords:

Sodium bentonite

Filler

Pozzolanic

Stabilized peat

Optimal mix design

ABSTRACT

Sodium bentonite is recognized as a natural pozzolan that can improve the mechanical properties of cemented materials due to its fineness and high content of silica and alumina. When mixed with cement paste in an appropriate amount, it is capable to impart pozzolanic effect which is vital to ensure continuous strength gain of cemented materials. Besides, the fineness of sodium bentonite enables the clay to bring filler effect on cemented materials, thus refining its pore spaces and reinforcing its structures. For stabilization of highly organic soil such as peat, research works that aim to quantify these effects with sodium bentonite as a natural pozzolan are relatively few. This article focuses on laboratory investigation on the application of sodium bentonite to maximize the filler and pozzolanic effects of stabilized peat. The outcome of the laboratory investigation is an optimal mix design of stabilized peat, which can be effectively applied to improve peat in a geological condition of swampy area for highway construction. Other than sodium bentonite, calcium chloride, Portland Composite Cement (PCC) and silica sand were used as additives to stabilize the peat sampled from Sri Nadi village, which is located in the area of Klang, Malaysia. To develop the optimal mix design, specimens of stabilized peat were tested in unconfined compression, direct shear and falling head tests. Both elemental composition and microstructure of the stabilized soil were examined using energy dispersive X-ray (EDX) apparatus and scanning electron microscope (SEM). It was found that test specimen of stabilized peat containing 10% partial replacement of PCC with sodium bentonite has the maximum unconfined compressive strength at 7 days of curing in water and under the application of 50 kPa initial pressure. Besides peat, the test specimen was formulated with a 300 kg m⁻³ binder dosage and a 596 kg m⁻³ silica sand dosage. At the same mix design, test specimens of stabilized peat have high values of cohesion, high values of angle of internal friction and very low rates of permeability, which are comparable to that of intact clay with a practically impervious drainage characteristic. Also, it was discovered that after testing, the test specimens showed a progressive increase in the direct shear parameters and a continuous decrease in the rate of permeability with increasing curing time in water. In the EDX and SEM analyses, high peaks of calcium, silicon, aluminum and oxide elements, and insignificant pore spaces of the stabilized peat were observed. This proves the existence of cementation products of mainly calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) crystals that were responsible to bind the organic and soil particles together to form stabilized peat.

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1. Introduction

Natural pozzolans have been widely used as substitutes for Portland cement in many applications because of their advantageous properties which include cost reduction and CO₂ emission reduction, decreased permeability and increased chemical resistance (Papadakis

and Tsimas, 2002; Rodriguez-Camacho and Uribe-Afif, 2002). A natural pozzolan is commonly identified as a highly vitreous and fine material which is predominated by silica (SiO₂) and alumina (Al₂O₃) in composition. It is applied to mitigate alkali silica reaction (ASR) in concrete by promoting secondary pozzolanic reaction during the initial stage of cement setting. In this aspect, the ultimate function of it is to neutralize the excessive alkalinity of cement with silicic acid (H₄SiO₄). One commercially available natural pozzolan is sodium bentonite.

Sodium bentonite is an absorbent aluminum silicate formed from the alteration of volcanic ash. Its chemical composition has a higher percentage of sodium oxide (Na₂O) than that of calcium oxide (CaO). It is

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identified as impure clay of predominantly montmorillonite in mineralogical composition as confirmed in the X-ray diffraction analyses of the studies of [Allo and Murray \(2004\)](#), [Ito and Komine \(2008\)](#), and [Ye et al. \(2010\)](#). The clay is known to possess physical properties such as small particle size, large surface area, high cation exchange capacity, high absorption capacity and high swelling capacity, which make it useful in many industries. Its compound of aluminum silicate is capable to hold a substantial net negative charge to induce large cation exchange capacity. Most of their useful characteristics are developed, or at least enhanced, when the charge on the layers is balanced by sodium ions ([Churchman et al., 2002](#)).

With such useful physical properties, sodium bentonite is commonly used as a natural pozzolan to partially replace cement in the production of cemented materials due to its high reactivity to calcium hydroxide liberated from cement hydrolysis for the generation of pozzolanic cementation bonds. Formation of such pozzolanic cementation bonds is known to ensure continuous strength gain and improve microstructure of cemented materials. When dispersed in cement paste, it is capable to generate a large number of nucleation sites for the precipitation of the hydration products ([Isaia et al., 2003](#)). Such mechanism contributes to densification and homogenization of the paste, resulting in its workability improvement, pore refinement and induction in pozzolanic activity. Furthermore, it functions as filler to improve the packing efficiency of cemented materials due to its fineness. For several decades, extensive research has been conducted on the positive effects of natural pozzolan on cemented materials such as concrete, mortar, brick and stabilized inorganic soils as evident in the studies of [Anisur Rahman \(1986\)](#), [Habert et al. \(2008\)](#), [Isaia et al. \(2003\)](#), [Sabir et al. \(2001\)](#), [Tangpagasit et al. \(2005\)](#), [Velosa and Cachim \(2009\)](#), and [Cristelo et al. \(2012\)](#).

However, research works on the application of sodium bentonite as a natural pozzolan to stabilize peat for highway construction are relatively scarce. This is mainly because of the difficulty at stabilizing the problematic soil due to its high organic content, water content and acidity. Advancement of cement chemistry in recent years has seen the possibility of using a variety of additives to stabilize peat. In addition to the function of sodium bentonite as a filler and pozzolanic additive, peat can be stabilized with calcium chloride as a cement accelerator, superplasticizer as a cement disperser, and silica sand as filler. In essence, the partial replacement of cement with sodium bentonite in stabilized peat offers an environmentally sustainable solution to reduce energy consumption of cement production, which in turn can reduce the effects of global warming and climate change. Cement industry generates around 5% of global CO₂ emissions, due to carbonate decomposition (about 50%), combustion of fuels in the kiln (about 40%) ([Velosa and Cachim, 2009](#)). It is estimated that each tonne of cement produces approximately 1 tonne of CO₂, mainly from the burning of fossil fuels and from the de-carbonation of limestone ([Rehan and Nehdi, 2005](#)). Therefore, it is a compelling idea to explore the novel usage of sodium bentonite as a natural pozzolan to optimize the strength and reduce the permeability of stabilized peat. The objective of this research work is to optimize the amount of sodium bentonite in stabilized peat so that a maximum pozzolanic activity and packing efficiency of the stabilized soil can be achieved. The optimal mix design can be applied to stabilized peat layer which functions as a shallow foundation to support highway embankment. In this way, an effective engineering response can be developed to such a geological condition of soft ground as peat. The mechanical behavior of the stabilized soil is evaluated in term of unconfined compressive strength, direct shear parameters and rate of permeability.

2. Geological formation and classification of the peat under study

The site of the peat under study is situated at Sri Nadi village in the state of Selangor in Malaysia ([Fig. 1](#)). Being part of the tropical peat

swamps covering the area of Klang which is located about 35.4 km away from Kuala Lumpur; the site consists of peat underlain by slightly organic grayish clay with sandstone as the bedrock. Based on the application of a peat auger to explore the soil at various points of the site, it was found that the depth of the peat ranges from 1 to 3 m. Such a depth range of peat implies that the soil can be categorized as moderately deep peat ([Lim, 1989](#)). The peat is characterized by high organic matter because it is formed from decaying plant which accumulated in water logged areas under acidic condition over thousands of years. It is a biogenic deposit which when saturated consists of about 90–95% water and about 5–10% solid material of predominantly organic matter ([Warburton et al., 2004](#)). The decomposition process of plant is rather slow due to retarded microbial degradation as a result of poor aeration in waterlogged areas. Such a slow decomposition process provides a positive environment for the formation of fibrous peat. The high water absorbing capacity of the peat influences the groundwater movement and this induces a condition for continuous accumulation of peat. Due to its high organic and water contents, the peat is extremely soft and compressible.

For the purpose of the peat physical assessment, six trial pits were excavated, each to a depth of 1 m below the ground surface to obtain both disturbed and undisturbed peat samples. Trial pits have the advantage of exposing the succession of strata for easy visual examination ([Whitlow, 2001](#)). Through naked-eye visualization of the trial pits, it was found that the groundwater table can be as close as 0.3 m from the ground surface depending on the rainfall pattern. Classification of the peat is done based on von Post scale degree of decomposition ([Landva and Pheeney, 1980](#)). von Post scale degree of decomposition is a peat classification system based on a combination of numerous elements namely surface vegetation, chemical properties, botanical origin, physical properties and genetic processes ([Andriess, 1988](#)). Altogether, there are ten degrees of decomposition in von Post scale ranging from H₁ (Fibrous and undecomposed) to H₁₀ (Amorphous and decomposed). After investigation, it was found that the peat can be classified to be in the range of H₃ to H₇, with the deeper the peat, the higher the degree of decomposition. The color of the peat was observed to vary between brown and dark brown. The peat can be further classified based on the classification of peat in American Society for Testing and Materials (ASTM) standard. [Table 1](#) shows the range values of basic properties of the peat. It can be inferred from [Table 1](#) that the peat has fiber content greater than 67%, ash content less than 5%, and pH value less than 4.5. By comparing such description with [ASTM \(2000\)](#) standard for peat classification, the soil can be classified as 'Fibric' with low ash content and described as highly acidic in term of pH.

3. Materials and methods

3.1. Description of the materials and laboratory mix designs applied for the peat stabilization

Materials utilized to stabilize the peat are Portland Composite Cement (PCC), calcium chloride, silica sand and sodium bentonite. The PCC is designed with an inclusion of 2% polycarboxylate based superplasticizer per unit weight of the cement to improve the cement workability by reducing water to cement ratio. Besides, the PCC is also enhanced with an addition of 4% calcium chloride by weight of the cement to accelerate the cement hydration process in the stabilized soil. To increase the solid particles and enhance the packing effect of the stabilized peat, well graded silica sand was prepared as filler for the peat stabilization. The particle size distribution of the well graded silica sand is tabulated in [Table 2](#). To assess an optimal filler effect of sodium bentonite, the clay was prepared at various compositions ranging from 5 to 40% for the peat stabilization.

The mix designs of stabilized peat for laboratory testing are shown in [Table 3](#). Altogether, 30 test specimens of stabilized peat of various

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