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Physico-mechanical behavior of self-cementing class C fly ash–clay mixtures

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Abstract

Self-cementing class C fly ashes are being increasingly used for soil stabilization of road bases and in other civil constructions. Because of their self-cementing capability in the presence of water, they can be used for clay subgrade improvement as cement surrogates, or as road subgrade material. However, for efficient and economic utilization of self-cementing class C fly ash, the physico-mechanical characteristics of these ashes must be determined extensively. This paper focuses upon the laboratory evaluation of the (1) stabilization characteristics of clay soils blended with self-cementing class C fly ash, and (2) residual self-cementation capabilities of ponded class C fly ash. Testing carried out by the authors and other researchers have indicated that curing time, curing condition, clay mineralogy, amount of fly ash and swelling potential in the soil-fly ash mix are the important variables that control stabilization characteristics. In this paper, the stabilization characteristics were evaluated in terms of the gain in the uniaxial compressive strength and stiffness, and swelling potential. To examine these effects, 12 set of mixtures of ideal clay soils with known percentages of kaolinite and montmorillonite, self-cementing class C fly ash and appropriate amount of water were compacted and cured. In the mixed samples, amount of montmorillonite varied from 0, 2, 4 and 6%, and the amount of self-cementing class C fly ash varied from 5, 10 and 20%. To investigate the effect of curing condition, three curing environments were used. For swelling test, the cured samples were inundated and allowed to swell at the seating pressure of about 2 kPa applied by the weight of the top porous stone and load plate using the one dimensional oedometer apparatus. In addition to the stabilization characteristics of clay soils-fly ash blend, the residual self-cementation capabilities of ponded class C fly ash were also investigated in terms of unconfined compression and CBR tests performed at 7 and 14 days of curing. Results obtained from these test were encouraging and compared favorably with the typical subgrade materials.

Keywords: Soil stabilization; Class C fly ash; Curing time; Clay type; Curing condition; Swelling potential; Wet-dry cycle; Ponded ash; Residual strength

1. Introduction

Electric utility companies in the United States produce a voluminous amount of classes C and F and other kinds of fly ashes by burning coal. According to a survey made by the [1], the total production of coal combustion product (CCP) in 2002 is 128.7 million tons, and the production increases at the rate of about 9% each year. Overall CCP utilization for 2002 was estimated at 45.5 million tons, or 35.4%. The disposal of this huge fly ash poses a serious problem in terms of land use and potential environmental pollution. To overcome this, strong economical and environmental imperatives exist for effective use of these fly ashes.

In the past few years, researchers tried to investigate the scope of commercial utilization of different kinds of fly ashes, and a wide variety of applications for high-volume use of fly ashes have been conceived [2–5]. In stabilizing soil for base construction, soil and cement mixtures were successfully used for decades. This is because of the high compressive strength of soil–cement mixtures, ease of construction, and may be, due to lack of knowledge regarding the alternate low-cost cementation materials. However, soil–cement mixture is subject to excessive cracking due to shrinkage, which may, decrease the expected life of the pavement. In contrary, bases stabilized with class F fly ash or non-graded fly ash are not subject to

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shrinkage cracking, and incur less capital investment with considerable result. To make class F fly ash more effective, some researchers added a small amount of lime in it. [6] have shown that the resilient modulus of a mixture of class F fly ash and lime is higher and plastic deformation is lower than that of class F fly ash alone. In the mixture of class F fly ash and lime, it is important to measure correctly the actual amount of class F fly ash and lime (additives) for proper strength gain. Plasticity index method, in such cases, can be used to measure the actual amount of additives ([7]). At present, there is no widely acceptable percentage of class F fly ash and lime in the mixture for base stabilization. However, researchers in India had shown that when soil is stabilized with 15% of lime and fly ash in proportion of 1:3 by weight, it enables an increase in CBR value from 4 to 20 and unconfined compressive strength from 1.34 to 6.8 kg/cm^2 [8].

Besides mixing with lime, class F or non-graded fly ash has also been used with tire chips in highway embankments [9]. However, before using tire chips with fly ash, it is important to evaluate leachability of the contaminants associated with tire chips. Strength gain of the soil stabilized with class F fly ash or non-graded fly ash in conjunction with lime or tire chips vary from place to place, and also depend on how accurately the experiment was conducted. Ultrasonic testing method, in such cases, can be used to evaluate the stabilized soil samples in the laboratory. The testing program consists of determining primary wave (P-wave) velocities of stabilized mixtures. Two main stabilization properties most frequently assessed are the dry density and compressive strength, which are conventionally measured by standard proctor test and uniaxial compression test, respectively. In ultrasonic testing method, trend of P-wave velocity can be correlated with the dry density and unconfined compressive strength at a moisture content that allows repeated assessment of a sample over time [10].

In addition to the class F fly ash, researcher also investigated the use of Illinois pulverized coal combustion (PCC) dry bottom ash for compacted landfill barriers and other geotechnical purposes. The properties of bottom ash are like the natural sand. The particle size of bottom ash ranges from fine gravel to fine sand with low percentages of silt and clay-sized particles [11–13]. For commercial utilization, the bottom ash needs to be treated with bentonite for effective utilization. For compacted landfill barrier, researchers found that the average value of hydraulic conductivity of Illinois PCC dry bottom ash treated with 15% bentonite content is close to the acceptable value required for its use as hydraulic barrier [11,12]. With 20% bentonite, the bottom ash bentonite mixture will have significant volume change that may not be acceptable for some lightly loaded structures. However, mixtures with 15% bentonite, compacted at initial moisture contents of 18% or higher may yield less than 4% volume change. For mixtures compacted at an initial moisture content of 16% or lower, the percent increase in volume change can be greater than 7% [14].

Recently, researchers have discovered the self-cementing capability of class C fly ash to modify the engineering properties of subgrade soil [15]. The self-cementing capability in class C fly ash is due to its high calcium oxide (CaO) content. The X-ray diffraction (XRD) and scanning electron microscopy (SEM) studies of stabilized clay with class C fly ash shows a reduction of the areas under the peaks, which are used to determine the strength gain. The SEM observations indicate a newly formed hydration products of calcium aluminum silicate hydrate crystals and a dense degree of packing as manifested by the substantial reduction of void areas as a result of stabilization [16].

Before claiming class C fly ash as a substitute of the existing cementitious material, researchers studied the suitability of class C fly ash against other materials such as lime for use in the base stabilization. In a study, [17] compared the lime and class C fly ash treated soils, and showed that in case of fly ash treatment, strength of stabilized soil is higher than that of lime treatment. However, the initial hydration process of class C fly ash is completed in about 30 min leading to the non-uniform strength gain. The rapid hydration of class C fly ash, some time, makes it impractical for use in high strength base course construction. The use of retarder, in such cases, may slow down the hydration process, and provide a uniform design strength gain of the treated soil [18]. Ferguson [19] carried out laboratory testing with compaction delay and using the retarder. The result showed that by reducing the compaction delay strength gain can be improved, and by increasing the retarder content, higher strength can be achieved.

Though class C fly ash has the self-cementing capability, the self-cementing capability varies with the percentage of CaO in it. Therefore, some researchers mixed lime with class C fly ash to make it more effective. Examples of bases stabilized with class C fly ash and lime mixtures are the highway base construction projects in Louisiana and Kansas. In Louisiana, bases were stabilized with lime-class C fly ash mixture as well as with the cement to compare their strength gain. The overall unconfined compressive strength for bases stabilized with lime and fly ash mixture was 30% lower than that of soil cement [20]. In Kansas, bases were stabilized with class C fly ash and the class C fly ash nixed with lime. The results of Superpave indirect tensile testing in the laboratory confirmed that the fly ash section had crack before the emulsion-plus-lime section [21].

One of the most common use of class C fly ash is in the stabilization of expansive subgrade soil. Several studies were conducted on this area, notably by [22–25]. These studies provided excellent data base for a statistical analysis of the properties of the stabilized materials. The study conducted by [23] also provided an added opportunity to evaluate the effects of cold weather stabilization.