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Technical note

Behavior of cement-stabilized fiber-reinforced pond ash, rice husk ash–soil mixtures

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ABSTRACT

In order to study the effect of addition of rice husk ash, pond ash, cement and fiber on the compaction and strength behavior of clay, a series of tests were performed. Modified proctor tests were conducted to evaluate the compaction behavior, while unconfined compression tests (UCS) and split tensile strength (STS) tests were conducted to evaluate the strength properties of clay. For testing purpose specimens were prepared with different amount of admixtures. Pond ash (PA) and rice husk ash were added to clayey soil at ranges of 30–45% and 5–20%, respectively. Polypropylene fibers of length 6 mm and 12 mm are used in this study with different contents as 0, 0.5, 1.0 and 1.5% by dry weight of mix whereas cement contents used are 0, 2 and 4%. To study the effect of curing on strength property, the specimens were cured for 7, 14, and 28 days and tested. Test results have shown that the maximum dry density decreases and optimum moisture content increases with the addition of admixtures, but fiber inclusion have marginal effect. The results shows that the inclusion of fiber reinforcement within un-cemented and cemented soil caused an increase in the UCS, STS and axial strain at failure, decreased the stiffness and the loss of post-peak strength, and changed the cemented soil brittle behavior to a more ductile one. Strength of clay improves by the addition of admixtures and fibers. The study has shown that combination of clay, RHA, PA, cement and fiber can be used as light weight fill material in different structures like embankment, retaining wall etc.

1. Introduction

Construction of buildings and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Improvement of certain desired properties like bearing capacity, shear strength (c and ϕ) and permeability characteristics of soil can be undertaken by a variety of ground improvement techniques such as densification techniques, reinforcement techniques and stabilization techniques.

1.1. Cement stabilization

Technology of treated soil by cement injection has become an alternative and economical solution for many geotechnical engineering problems, such as road and railways construction. The technique is based on mixing cement with soil, which the soil to become more resistant. Indeed soils, depending on their type, can be stabilized using different sorts of binders like lime and cement. However recent studies have shown the interest of using lime, together with coal fly ash for the pozzolanic reaction, to stabilize subgrade soil or granular base under pavements or foundations (Beeghly, 2003). Strength characteristics are reached faster with cement addition, however cement treated soils are more prone to shrinkage and cracking when used as a base course (Gray et al., 1994; Shirazi, 1999).

1.2. Fiber-reinforced soil

Fiber inclusions cause significant modification and improvement in the engineering behavior of soils. A number of research studies on fiber-reinforced soils have recently been carried out through triaxial tests, unconfined compression tests, CBR tests, direct shear tests, and tensile and flexural strength tests (Freitag, 1986; Maher and Gray, 1990; Al-Refeai, 1991; Fatani et al., 1991; Maher and Ho, 1994; Ranjan et al., 1996; Nataraj and McManis,

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1997; Consoli et al., 1998, 2002, 2005; Santoni et al., 2001; Kumar et al., 2005; Casagrande et al., 2006, 2007a, 2007b; Kim et al., 2008; Park, 2008; Bera et al., 2009; Fatahi et al., 2012; Divya et al., 2014; Li et al., 2014; Anggraini et al., 2014; Botero et al., 2015). One of the primary advantages of randomly distributed fibers is the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher and Gray, 1990). The literature cites various studies conducted to understand the behavior of soils modified by the addition of fibers and other components. Consoli et al. (1998) carried out drained triaxial compression tests to study the individual and combined effects of cement stabilization and randomly oriented fiber inclusions on the behavior of silty sand. Consoli et al. (2002) conducted unconfined compression tests, splitting tensile tests, and saturated drained triaxial compression tests to evaluate the benefit of utilizing randomly distributed polyethylene fibers obtained from plastic wastes, alone and combined with rapid hardening Portland cement to improve the engineering behavior of uniform sand. Kumar et al. (2005) found that unconfined compressive strength of highly compressible clay increases with the addition of fibers and it further increases when fibers are mixed in clay sand mixtures. Park (2008) studied the effect of fiber distribution and concentration on the strength of fiber-reinforced cemented sand and concluded that the strength of fiber-reinforced cemented soils depends not only on the degree of fiber reinforcement and distribution but also on the amount of fiber used in the specimen. Fatahi et al. (2013) carried out bender element tests on 126 cylindrical samples of cement-treated kaolinite and bentonite clays with various cement and fiber (polypropylene and recycled carpet) contents to discern the relationship between fiber and cement content and the small-strain mechanical properties, including the shear wave velocity and maximum small-strain shear modulus of treated soils. Cristelo et al. (2015) carried out ultrasonic wave and uniaxial compression tests to measure P-wave velocity and compression strength in cement-stabilised sandy–clay reinforced with polypropylene fiber. Tests results indicated that stiffness and compression strength of sandy soil, increases with cement and fiber content. Correira et al. (2015) studied the effect of binder and polypropylene fiber quantity on the mechanical behavior of soft soil; results reveal that the increment of binder quantity improves the stiffness, the compressive and the tensile strength of the soil; however, the presence of fibers may reduce this beneficial effect.

1.3. Pond ash/rice husk ash stabilization

Huge quantities of fly ash and bottom ash are produced as by-products from coal based power plants all over the world. In some countries, such as India, the ash is usually disposed in ash ponds in the vicinity of plants. Pond ash deposits are characterized by very low density, poor bearing capacity, and are considered unsuitable for supporting any structural load. The ash ponds, when their capacity is exhausted, are abandoned, creating vast flat barren lands. In India, at present, millions of tons of pond ash are deposited in such abandoned ash ponds that cover up nearly 20,000 ha of land. Moreover, the leachates, emanating from the ash ponds, carry toxic elements and heavy metals that may lead to contamination of surface water and groundwater bodies, as well as soils.

Several attempts have been made to improve the engineering properties of pond ash by adding lime/cement by mechanical mixing. Kumar et al. (1999) gives the results of laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers. The test results reveal that the inclusion of fibers in soils increases the peak compressive strength, CBR value, peak friction angle, and ductility of the specimens. Sarkar et al. (2012) reported improvement in California bearing ratio of pond ash with different percentage of cement. Bera Ashis Kumar (2013) reported that with the increase in pond ash content (0%–30%) of the pond ash mixed soil, the value of unconfined compression strength decreases significantly, whereas, with addition of pond ash (above 40%) the changes of unconfined compression strength of pond ash mixed soil is not appreciable. Bera et al. (2007) reported that with the increase in compactive efforts, MDD increases and at the same time OMC decreases. Chand and Subbarao (2007) presented the effects of lime stabilization on the strength and durability aspects of a class F pond ash, with a lime constituent as low as 1.12%, are reported. Lime contents of 10 and 14% were used, UCS increased with increase in lime content. Ghosh (2010) presents the laboratory test results of a Class F pond ash alone and stabilized with varying percentages of lime (4, 6, and 10%) and Phosphogypsum (0.5, and 1.0), to study the suitability of stabilized pond ash for road base and sub-base construction.

Rice husks are the shells produced during de-husking operation of paddy, which varies from 20% (Mehta, 1986) to 23% (Della et al., 2002) by weight of the paddy. The rice husk is considered as a waste material and is being generally disposed of by dumping or burning in the boiler for processing paddy. The burning of rice husk generates about 20% of its weight as ash (Mehta, 1986). Silica is the main constituent of rice husk ash (RHA) and the quality (% of amorphous and un-burnt carbon) depends upon the burning process (Nair et al., 2006). The RHA is defined as a pozzolanic material due to its high amorphous silica content (Mehta, 1986). In India, the annual production of paddy is about 100 million tonnes, thereby generating more than 4 million tonnes of RHA (Ramakrishna and Pradeep Kumar, 2008). Rice husk ash cannot be used alone for stabilization of soil due to lack of cementitious properties (Haji Ali et al., 1992). So it is used along with a binder like Lime, cement, lime sludge, Calcium chloride etc. for stabilization of soil (Muntohar and Hantoro, 2000; Haji Ali et al., 1992; Basha et al., 2005; Brooks, 2009; Sharma et al., 2008).

Many experimental studies on the geotechnical characteristics and chemical stabilization of pond ash and rice husk ash are reported in the literature. However, information about the effect of fiber inclusions on the geotechnical characteristics of Pond ash and rice husk ash is scarce.

The use of RHA and pond ash in soil stabilization can lead to low-cost construction and can provide an environmentally friendly means of their disposal. Increased use of such materials would reduce the use of cement and also represent savings in energy and greenhouse gas emissions.

The present study involves the stabilization of clayey soil by mixing pond ash, rice husk, cement, fibers and their combination to improve the engineering properties. The effect of proctor compaction test, compressive strength and Split tensile strength test were performed.

1.4. Scope of present study

The geotechnical characteristics of clay mixed with pond ash, rice husk ash, cement and randomly distributed fibers were investigated. Cement was added to soil mix at 0–4%, pond ash and rice husk ash were added to the clay at 30–45% and 5–20% by dry weight of sample. Samples were tested with 0%, 0.5%, 1.0%, and 1.5% plain polypropylene fibers of 6 mm and 12 mm length. Test specimens were subjected to compaction tests, unconfined compression tests, and split tensile strength tests. Specimens were cured for 7, 14, and 28 days after which they were tested for unconfined compression tests and split tensile tests. This paper presents the details and results of the experimental study and the conclusions from the study.