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Cement kiln dust and fly ash blends as an alternative binder for the stabilization of demolition aggregates

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HIGHLIGHTS

- Cement kiln dust and fly ash blends evaluated as an alternative binder.
- Cement kiln dust in combination with fly ash to stabilize demolition wastes.
- Strength and stiffness testing.
- 20% cement kiln dust with 10% fly ash found to be optimum content for stabilizing demolition wastes.

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ABSTRACT

Cement kiln dust (CKD) is an industrial by-product formed during the manufacture of cement. Fly Ash (FA) is the by-product of coal-fired electricity generation. Construction and Demolition (C&D) materials are alternative aggregates used in construction applications. CKD is calcium-rich whereas FA is silica-rich, hence the unique combination of these two pozzolanic materials (CKD + FA) were investigated as an alternative binder to stabilize C&D materials. The usage of CKD + FA to stabilize C&D aggregates comprised of Recycled Concrete Aggregate (RCA), Crushed Brick (CB) and Reclaimed Asphalt Pavement (RAP) will have environmental and economic benefits. The strength characterization of CKD + FA stabilized C&D materials was evaluated by undertaking Unconfined Compressive Strength (UCS) tests. The durability of the CKD + FA stabilized C&D materials under simulated loadings was evaluated by Repeated Load Triaxial (RLT) tests to determine the resilient modulus (M_R). The optimum performance for stabilizing C&D materials was obtained at the mix design with 20%CKD + 10%FA.

1. Introduction

Cement kiln dust (CKD) is an industrial by-product formed during the manufacture of cement and is a waste material that is traditionally destined for landfills [1]. CKD is captured and collected in particulate devices such as baghouses, electrostatic precipitator and cyclones [2]. Approximately 14.2 million tons of CKD are generated in the United States each year of which 4.3 million are stockpiled [3]. In addition to the massive CKD by-products generated by the cement manufacturing industries, there is an abundance of CKD stockpiles worldwide [4]. Almost all CKD products are generally nonhazardous and exhibit a moderately low leaching potential for toxic metals [4]. However, the increasing stockpiles of CKD generated annually and high cost of landfilling requires innovative solutions to be developed to utilize CKD in construction activities.

CKD as a rich source of calcium can be utilized to complement the alumina and silica source of class F FA to create aluminium-substituted C-A-S-H type gel and zeolites like gismondine which can be created in high calcium content binders with high Al_2O_3 and low MgO [5,6]. Including a rich calcium source to the mixture of a CKD/FA binder can potentially significantly enhance the strength and texture and of the binder gel [6]. The variable characteristics of CKD as an industrial by-product is a major setback for utilization of this binder for stabilization activities [1,2]. However,

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the free lime content can be used as a controlling parameter to measure the competence of CKD products [1]. In addition, the sulfate content, alkali content and pH of the solution and the fineness of the CKD dust powder can potentially significantly influence the stabilization process. It should be noted that calcium based binders perform best when mixed with highly plastic soils. The high content of free lime (CaO) in CKD increases the alkalinity of the solution. Fly Ash (FA) is the by-product of coal-fired electricity generation in many developed and developing countries, and is traditionally stockpiled as a waste material at power plants.

The demand for natural aggregates in construction projects is consistently rising with the rapid increase in infrastructure projects in developed and developing countries. Natural quarry materials are increasingly scarce and furthermore, the environmental concerns and economic costs of using these limited resources is increasing rapidly. In recent years, there has been increased utilization of Construction and Demolition (C&D) materials in civil engineering projects as replacement for conventional construction aggregates [7]. Utilization of C&D materials has been pursued increasingly, as this approach enables the preservation of natural aggregates [8] as well as significant environmental and economic savings for the community [9]. In addition to lower cost and environmental burden of using recycled C&D materials such as crushed brick (CB) and recycled concrete aggregates (RCA) [10], the in situ recycling of Reclaimed asphalt Pavement (RAP) has been reported to yield savings of up to $1 million per kilometer length of each highway lane [11].

The hitherto unknown properties of C&D materials requires further fundamental understanding in order to utilize these waste materials in geotechnical applications [9,12]. Partial inclusion of C&D aggregates as conventional construction materials has been adopted in recent years [13,14]. Improving the strength and stiffness of the C&D aggregates has been achieved and implemented by stabilization techniques by using cement [10]. However, the economic and environmental cost of stabilization activities due to excessive usage of high carbon emitting Portland cement has been recognized as a major setback [12]. Lime and cement have been successfully used for stabilization of C&D aggregates [15–18], as have other conventional binders [19–21].

Developments of low-calcium alkali-activated binders were initially implemented as a fire-resistant replacement for organic polymeric materials with a potential strength development in structural applications [22]. The development of crystallization of alumina-silicate gel created in low-calcium systems of alkali activated materials has shown comparable strength [23]. However, the lack of confidence in traditional binder synthesis [24], in addition to cost of activators resulted in the development of calcium-rich binders in stabilization and concrete production works [25]. Bassani, Riviera [26] reported on significant improvement in mechanical properties of long-term CKD stabilized wastes.

CKD is calcium-rich whereas FA is silica-rich, hence the unique combination of these two pozzolanic materials (CKD/FA) were investigated as an alternative binder to stabilize C&D materials. The strength and resilient moduli properties of CKD/FA stabilized C&D materials were evaluated in this research to develop an understanding of the properties and efficiency of CKD in construction stabilization activities. The successful performance of CKD as an alternative binder in combination with FA to stabilize C&D aggregates, would enable CKD to be utilized in low-carbon civil construction activities.

2. Materials and methods

CKD was obtained locally from a cement manufacturing company. The FA used in this research was black coal, low calcium class F type FA. CKD + FA stabilized C&D aggregates with up to 30% binder contents were evaluated to ascertain the optimum CKD content. The C&D materials used in this research were collected from a local recycling site near Melbourne with a nominal size of 20 mm.

An extensive laboratory characterization was performed on the CKD + FA stabilized C&D materials to characterize these waste materials. Tests undertaken included particle size distribution, pH, modified compaction, permanent deformation, Repeated Load Triaxial (RLT) and Unconfined Compressive Strength (UCS). The size distribution of the aggregates were determined according to Australian standards [27]. Due to relatively high water absorption of CKD, the optimum moisture content and maximum dry density of the CKD + FA stabilized C&D materials were determined with use of modified compactive energy to simulate the high density of the stabilized materials [28].

The pH value of the unbound as well as the stabilized materials after mixing were measured according to Australian standards [29] to investigate the alkalinity of the environment. The stabilized samples were compacted in a split mold, to avoid possible damage to samples during the removal of the specimen, with diameter of 100 ± 1 mm and 200 ± 1 mm in height. Samples were compacted in 8 layers with modified compactive energy obtained from compaction test. the surface of each layer was deeply scarified to achieve interlocking between the layers and avoid anisotropy in the sample. The samples were cured in a humidity box for 7 days at room temperature and at a relative humidity of 97% to 99%.

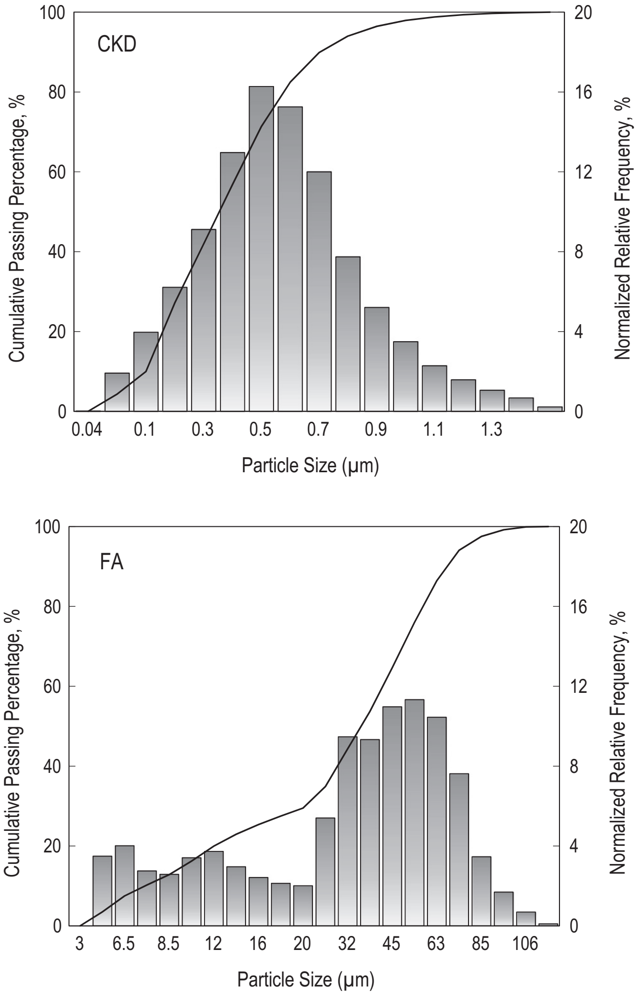

Fig. 1. Particle size distribution of (a) CKD and (b) FA.