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Alkali-activation of fly ash and cement kiln dust mixtures for stabilization of demolition aggregates

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HIGHLIGHTS

- A combination of CKD and FA was evaluated as an alternative low carbone binder.
- CKD complents FA and creates better cementatious products.
- A CKD:FA ratio of 50:50 found to be the optimum binder content.

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ABSTRACT

Utilization of industrial by-products such as cement kiln dust (CKD) and fly ash (FA) for increasing the strength and stiffness of demolition waste aggregates can be an optimal and sustainable solution for reducing the carbon footprint of the construction activities. Furthermore, this approach of incorporating waste materials as construction materials will also reduce the rapid depletion rate of natural resources. This research presents an optimization, by means of evaluating combinations of CKD + FA blends to utilize the rich source of calcium and silica and alumina in these by-products. The impact of sample preparation method is investigated. The use of alkaline solutions facilitates the progression of activation process in room temperature. Recycled Concrete Aggregate (RCA), Crushed Brick (CB) and Reclaimed Asphalt Pavement (RAP) are three major components of the demolition waste stream and were used as the parent materials in this research for assessment of the efficiency of stabilization process. The durability of the stabilized materials under repeated loading was investigated. In addition, the resilient modulus of the stabilized materials were compared with the empirical models to assess the impact of confining stress and deviatoric stress on the moduli of the mixtures. The optimum ratio of FA:CKD of 50:50 showed the highest performance. The research indicates that alkali-activation of 15%CKD and 15%FA blended with C&D aggregates provided the optimum blend for the usage of these wastes as construction materials.

1. Introduction

The rapid rate of depletion of natural resources in the modern societies and the high magnitude of waste generated has motivated research in recent years into alternative sustainable construction materials [1]. The target of green city design is mainly reducing the waste generation and reusing the generated waste [2]. Construction and demolition (C&D) aggregates currently account for a significant proportion of wastes directed to landfills. Reuse of materials in the structures that reached their end of life not only reduces the consumption of natural aggregates, but also reduces the amount of waste sent to landfills [3]. The crushing and screening process of the end-of-life materials creates pulverized materials from ash size to gravels that can be used in a variety of applications [4,5]. The uncertainty related to quality of crushed C&D aggregates brings along the reluctance of industrial sector to use these aggregates in construction activities [6]. In 2015, 20 Megatons of C&D aggregates were generated in Australia alone.

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Recycled concrete aggregates (RCA), crushed brick (CB) and reclaimed asphalt Pavement (RAP) comprise the largest portion of the C&D waste stream [7].

Preliminary research into the chemical stabilization of C&D aggregates has indicated a reliable product for industrial applications, if sufficient research is undertaken into their engineering and strength properties. However, successful use of general Portland cement for increasing the strength is counterproductive in reducing the carbon footprint of the end product [8]. Hence, use of industrial by-products, which possess pozzolanic characteristics for chemical stabilization, can lead to ultimate solution of sustainable depletion of C&D landfills and redirecting a considerable portion of C&D aggregates as well as the industrial by-products from landfills [9].

Cement Kiln Dust (CKD) is a very fine dust that can be collected from baghouses, electrostatic precipitator and cyclones used for cement production [10]. CKD is the side product of cement manufacturing and is typically landfilled [11]. In addition to enormous existing stockpiles, it is estimated that annually 14.2 million tons of CKD are produced in the United States [12]. CKD exhibits low leaching potential for toxic metals and is rich in calcium [13]. Low calcium class F type FA, which is high in silica is also a by-product that is destined to landfills and is available in abundance [14]. The high calcium content of CKD can be complimented by the high silica content in fly ash (FA) for development of high-calcium alkali activated materials [15]. It should be noted that variability of CKD is an obstacle for the utilization of this waste material in large quantities [10,11,16]. However, constant monitoring of the active calcium content and pH level of CKD sources can be used in modifying the alkali-activated system design [11,17]. The strength properties and rate of strength gain of the mortars utilizing CKD and FA have been studied previously by some researchers [18–20]. This research investigates the impact of using alkali activated CKD and FA stabilization on a granular media at an optimum moisture content. The low water content is required to avoid the need of containment after compaction in the field applications.

Chemical stabilization of C&D aggregates with industrial by-product generally requires an accelerator like temperature curing to expedite the activation process [21]. However, providing a alkaline environment can activate the amorphous silica in fly ash particles and by cation replacement, form an aluminosilicate gel and aluminum- substituted C-A-S-H type gel [22]. The combination of CKD and FA activated in an alkaline environment was investigated in this research to evaluate their viability for the strength development of stabilized C&D materials. This research provides an in-depth understanding of the sensitivity of strength development in alkali activated C&D materials due to the curing environment, moisture content and mixture ratios. In addition to monitoring the variation of strength and resilient modulus of the mixtures, the chemical composition of mixtures were monitored to identify the formation of various gel types.

2. Materials and methods

RCA, CB and RAP with nominal size of 20 mm was supplied from a recycling facility near Melbourne, Australia. The stabilization process was targeted to increase the strength and durability of the recycled materials for higher end construction activities. Accordingly, low calcium class F type FA was procured from a local supplier that supplies the FA from a power plant utilizing black coal. CKD was collected from a cement manufacturing company. The total amount of CKD + FA binder was limited to 30%, which has been identified previously as the upper limit for binder content [23]. To accelerate the process of production of aluminosilicate gel in slow cementitious blends and to increase the overall pH of the mixture, a composition of sodium silicate and sodium hydroxide was used. 8 M sodium hydroxide solution (NaOH) and Grade D sodium silicate solution (Na_2SiO_3) with a molar ratio of 2.0 ($M_s = SiO_2/Na_2O$, Na_2O = 14.7% and SiO_2 = 29.4%) were used for the activation process.

The final product was targeted to be a self-sustaining mixture that is compacted for road base/subbase and hence the moisture content in the system was limited to avoid slump in the mixtures. A suite of laboratory experiments were performed for characterization of C&D aggregates as well as the industrial by-products.

Particle size distribution of both aggregates and binders was determined using sieving method in accordance to Australian standards [24] and for the Cilas particle size analyzer, respectively. The optimum moisture content (OMC) and maximum dry density (MDD) of the C&D aggregates mixed with CKD + FA was determined in accordance to AS 1289.5.2.1 [25] for each mixture in account of high water absorption of CKD. The mixture of C&D aggregates and CKD + FA was compacted in a split mold according to the relative MDD and OMC in 8 layers to form samples with a diameter of 100 ± 1 mm and height of 200 ± 1 mm.

The high moisture absorption of granular material particularly, CB and RCA can impact the activation process by absorbing the moisture needed in the curing period [26]. Hence, the aggregates were mixed with 30% of the design moisture and were cured 3–4 h before compaction. The remaining water was used to mix with the combination of NaOH and Na_2SiO_3. The total moisture content of mixture included the moisture used for preparation of alkaline solution and was targeted to add up to the OMC obtained from compaction tests. The dry binders were mixed thoroughly and were later mixed with the diluted alkaline activator to create a lean mortar. Controlling the moisture content in the preparation and mixing routine

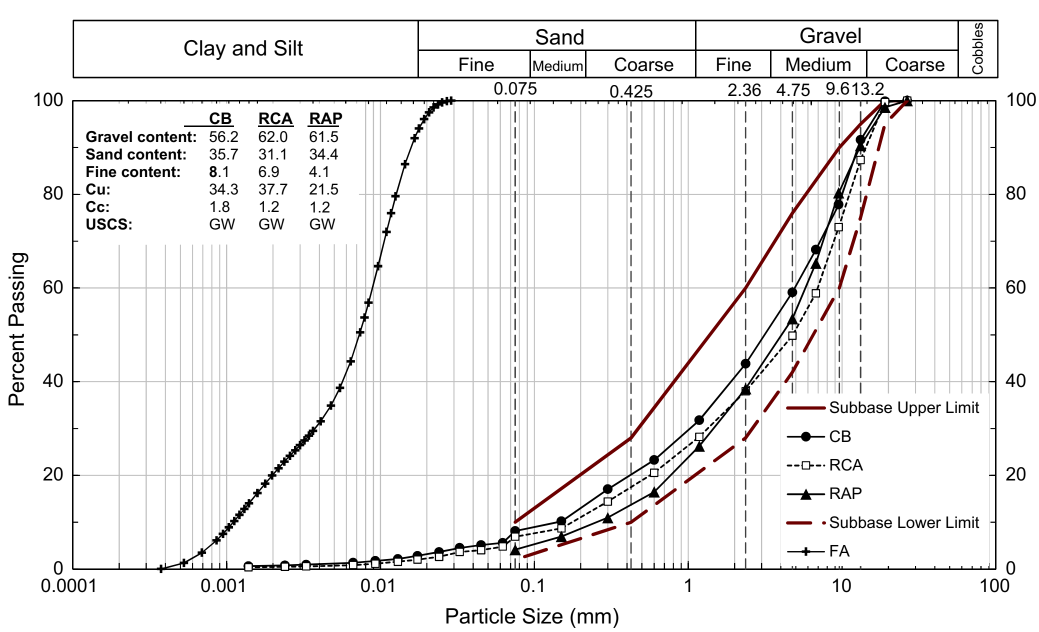

Fig. 1. Particle size distribution of unbound C&D materials and FA.