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Review

Influence of coal bottom ash as fine aggregates replacement on various properties of concretes: A review

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ABSTRACT

In the current phase, the engineering and construction industry has successfully engaged in a challenge for consuming “sustainable, green and recycled products” in manufacturing of concrete. The utilization of Coal Bottom Ash (CBA) in concrete industry is one of the best feasible options to minimize the environmental concerns raised due to its presence. The use of CBA in manufacturing of concrete has been increased in last decade. Coal bottom ash has a potential to be used as concrete material in place of fine aggregates. The present investigation has focused on reviewing some of the fresh, mechanical and durability properties of Normally Vibrated Concrete (NVC) and Self-Compacting Concrete (SCC) made with incorporation of CBA as replacement of fine aggregates. Most of the studies have described that the use of CBA lowers the overall performance of NVC/SCC, whereas few of them have reported its successful use in attaining similar/better performance to that of the concretes made without incorporation of CBA.

1. Introduction

Concrete’s versatility, durability, sustainability and economy has made it the worlds most widely used construction material. It has been expected that every concrete structure is going to maintain its required strength and serviceability over the entire course of its service life. Such a requirement implies that, concrete must be able to resist most of the deterioration processes to which it may be subjected during its designed life. Concretes able to withstand against various deterioration processes are generally treated as durable. There may be internal as well as external causes through which the exposed concrete can be deteriorated. Inadequate durability in concrete can be due to physical, chemical or mechanical aspects. It has also been well recognized that the major cause for the reduction in the overall performance of any type of concrete is due to the lack in durability. In reference to durability aspects, permeability and the pore system in concrete has profound influence on the durability properties of concrete (Sideris and Anagnostopoulos, 2013; Quinn and Bartos, 2002).

A new trend in designing complex and heavily reinforced structures showed that compaction of concrete by vibrating may be difficult in some cases and is strongly depend on human factor. It has been noticed many times that after the removal of formwork the laid concrete has not spread to all the positions in uniformity. The aforementioned aspect and some other limitations have encouraged to the development of Self Compacting Concrete (SCC). Self-Compacting Concrete with excellent deformability and segregation resistance has resulted in increase its demand for last couple of decades. It is a special kind of concrete which flows and fills the formwork and passes through the restricted spacing of congested reinforcement without segregation and external compaction (Calado et al., 2015; Sukumar et al., 2017). The aforesaid advantages result in reduction of time, noise pollution, improves working environment and open the way for automation of the concrete construction. It has been estimated that use of SCC outcomes in more durable construction compared to that of Normally Vibrated Concrete (NVC) (Tamilarasan and Sankaran, 2015; Teja et al., 2017). Nowadays, SCC has become more popular and demandable worldwide due to its overall improved performance. Generally, SCC components are typically identical to NVC with sometimes high content of different cement additives (Fly Ash (FA), Limestone Powder (LP) etc.) as replacement of Portland Cement (PC). Fly ash is a by-product generated from coal thermal power plants along with CBA while LP is produced by crushing and grinding of calcite limestone (Arrigonia et al., 2018; Kaur et al., 2012). In addition to above, the variation of nature of aggregates resulted in improvement (fine with Coal Bottom Ash (CBA) or copper slag etc.) and in sometimes degradation (coarse aggregates with Recycled Concrete Aggregates (RCA)) of mechanical and durability properties of the SCC (Hussain et al., 2013; Dash et al., 2016).

In addition to above, it has been noticed that, limited amount of

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construction and demolition (C&D) wastes are recycled and used as in form of RCA (coarse RCA and fine RCA) in manufacturing of new concrete. Since the amount of C&D wastes are regularly increasing, there are many reasons for focusing on methods that promote an increase in the recycling of C&D wastes. Recycled concrete aggregates include crushed, graded inorganic particles (both coarse and fine) which are obtained from treated/untreated old C&D wastes (Subhash et al., 2015). It has been reported that the configuration of wastes generated from different forms of ashes (like FA, CBA etc.,) is well structured world-wide whereas different standards for every country have been reserved for C&D wastes (Martosa et al., 2018). A significant amount of research has been done earlier which promote the use of C&D wastes (RCA) as well as industrial wastes (mainly CBA) in the manufacturing of the concretes. Such approach has led to the conservation of natural resources and encourages the sustainability in the current and future concrete industry. At present, the natural assets in form of natural aggregates are diminishing globally due to an uncontrollable demand for raw materials (Bayatia et al., 2018).

The current paper reviews some of the important investigations which focuses on fresh, mechanical and durability properties of the NVC and SCC made with incorporation of CBA at different replacement levels of fine aggregates.

2. Coal bottom ash

The use of CBA probably maintains the overall economy in the upcoming construction and can reduce the depletion of natural resources (Rafat, 2014; Kim, 2015). Coal bottom ash is one of the biggest sources of industrial wastes that have been produced from thermal power plants (Nikbin et al., 2016; Baite et al., 2016; Kim and Lee, 2015). On burning of coal in coal fired boilers, it leaves behind the various types of ash, some of which are removed from the bottom (due to coarser in nature) of the furnace (generally known as CBA) and the remaining has been collected in other forms like FA and scrubber ash (Kim and Lee, 2015; Sharma et al., 2012; McMahan et al., 2002). The various features and handling methods for FA and bottom ash have been convened thoroughly in earlier investigations (Huang et al., 2017; Yang et al., 2015). In India, around 68% of electricity has been produced by the coal fired thermal power plants. Typically, burning of approximately 15–20 tons of coal generates, about 1 MW of electricity as well as 15–20% of CBA alone. In total, India is producing approximately 105 million tons of coal ash annually which includes about 35 million tons of CBA alone (Dinesh et al., 2016). Disposal of CBA has already become a major problem due to scarcity of dumping sources and increasing environmental hazards in India and in rest of the world.

2.1. Applications of coal bottom ash

It has been observed that CBA which is obtained after burning of different coal forms like lignite, sub bituminous, bituminous, anthracite etc. has some of the additional pozzolanic properties which further promotes its use in the construction industry (Kim and Lee, 2015). The practice of disposing off CBA has proved to be unfavourable in the current period not only due to the increase in cost of disposal, but also due to various health hazards. The aforementioned concerns can be probably relieved by reusing and recycling the generated wastes (CBA). The surface texture and more or less pozzolanic behavior of the CBA favours its potential application in field of civil engineering works such as road and embankment construction, material replacement (fine aggregates), manufacturing of construction materials (bricks, fire-proof products, ceramics, etc.) (Ramme and Tharaniyil, 2013). Many field studies have been conducted on CBA for pavement constructions (base, sub-base and flexible pavement constructions) as well as embankment constructions. Coal bottom ash can be used efficiently through waste management (waste water and hazardous wastes) options like soil stabilisation, waste solidification, agricultural purposes, etc. (Jayaranjan et al., 2014; Mohammed and Karim, 2017; Cadersa et al., 2014). Some earlier investigations have substantiated that CBA can be effectively incorporated in the construction of pavements made with stone mastic asphalt without compromising the rutting resistance (Pasetto and Baldo, 2014a). Likewise in a similar study, incorporation of CBA during construction of stone mastic asphalt pavements, the fatigue performance has been improved while the macro-crack initiation has been delayed (Pasetto and Baldo, 2014b).

2.2. Health hazards and environmental concerns of CBA

The methods of open disposal of CBA from the various industrial sectors and thermal power plants lead to major environmental pollution as well as various health hazards. Laura et al., 2009 conducted the chemical analysis of CBA in which the percentage content of various metals like copper, zinc, arsenic, barium, nickel, mercury etc. have been evaluated. The observed quantity of aforementioned metals have been compared with the recommendations described by various organizations. It has been concluded that the desired concentration of copper, zinc, arsenic, barium and nickel as contained in CBA has been found to be 3–4 times higher to that of the permissible values [(from 16.6 to 46.2 for copper, 12.5 to 40.4 for zinc, 20.4 to 74.6 for arsenic, and 8 to 23 for nickel (in mg/kg)]. Likewise, identical interpretations for the concentrations of the heavy metals have been observed by Pasetto and Baldo (2014a). The recent researches confirm that 'transition metals' like copper and zinc in form of fine particles are key causes for damaging lung tissues. Moreover, coal ashes (both CBA and FA) are classified as a Group-I human carcinogen and are associated with increased risks of skin, lung, and bladder cancers. In addition to above, CBA directly affects the red blood cells which are present in humans as well in animals. The presence of CBA particles causes swelling and altering of cardio-pulmonary organs (e.g. pulmonary vasculitis, hypertension). Cenni et al. (2000) confirmed that the arsenic (which is present in CBA) exposure to humans increased the risks of skin, lung, liver, breast and bone cancer. However, the comprehensive injuriousness of CBA particulates and their effects on human health, environmental fate and impact in water and soil, is still largely unknown due to a lack of information on the rate at which they are entrained into the atmosphere. Presence of 'heavy metals' in CBA and its high solubility results in contamination of surface and sub-surface water resources near to the CBA piles (Silva and da-Boit, 2011). Re-suspension of CBA particles in the atmosphere which are enriched with toxicity leads to pollution of air and thereby severe breathing problems.

2.3. Physical properties of CBA

From the laboratory observations, it has been observed that CBA is dark grey material with most of the angular particles in shape. Coal bottom ash has been treated as porous material with rough surface texture and less unit weight (Pasetto and Baldo, 2014a). It has been noticed that the size of CBA affects the mechanical and durability properties of concretes as different thermal power stations produce CBA of different properties. The overall performance indirectly depends on the grain size distribution of CBA. Due to similar/identical particle size distribution, CBA has been successfully replaced with fine aggregates in manufacturing of NVC and SCC for last decade. Depending upon the different sources of the combustibles and rate of combustion, the particle size distribution of CBA varies as quoted in earlier investigations which consequently affect the overall performance of CBA (Fig. 1). Generally, the grain size of CBA particles resembles to the grain size of fine aggregates with low percentage of silt-clay. The CBA has a higher percentage of fine sand and a lower percentage of medium to coarse sand as compared to the fine aggregates (British Standard Institution, 1992). Furthermore, the other properties like percentage of water absorption, specific gravity, and fineness modulus of CBA have shown variety of results in several investigations. The details of these