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Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete

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ABSTRACT

Large quantity (35 million tons) of coal bottom ash is produced by thermal power plants in India. The present method of disposal of coal bottom ash on open land is the main cause of an environment hazard for the surrounding community. As utilization of coal bottom ash can help in alleviating environmental problems, thus the present work was done to explore the possibility of its use as sand replacement in concrete manufacturing. Two types of control concrete mixtures to develop 28 d compressive strength of 38 MPa designated as concrete 'A' and 34 MPa designated as concrete 'B' were made with river sands having different fineness of modulus. In both grades of concrete mixtures, sand was replaced with coal bottom ash at 20, 30, 40, 50, 75 and 100% levels. Workability and bleeding of concrete decreased on use of coal bottom ash as fine aggregate. Test results show that compressive and splitting strength of concrete mixture 'A' did not changed significantly when sand having fineness modulus of 1.97 was replaced with coal bottom ash. However, in case of concrete mixture 'B', when coal bottom ash was used as replacement of sand having fineness modulus of 2.58, the compressive and splitting tensile strength of bottom ash concrete decreased at early curing age. After 90 d of curing age, compressive and splitting tensile strength of bottom ash concrete mixtures was almost comparable to that of control concrete mixture. Bottom ash concrete mixtures displayed lower modulus of elasticity and abrasion resistance as compared to control concrete mixture. Abrasion resistance of bottom ash concrete mixtures improved significantly with age. Pulse velocity through bottom ash concrete mixtures indicates that good quality concrete can be made with coal bottom ash as replacement of either type of sand.

1. Introduction

In India, about 173 million tons of coal ash is produced on combustion of 524 million tons of coal by 143 no. thermal power plants (CEA, 2014). It includes about 35 million tons of coal bottom ash collected at the bottom of furnace. Coal ash is mainly due to presence of rock detritus in the fissures of the coal seams. On combustion of coal, the combustible matter burns and incombustible material such as rock detritus etc. result in coal ash. The variability in rock detritus from one source to another therefore causes variation in the properties of coal ash as well. Coal ash extracted from the boiler flue gases is called fly ash and the coarser part collected at bottom of the furnace is called coal bottom ash. Fly ash is finer than cement and is used as cement supplementary material in production of concrete. In India, fly ash is used in manufacturing of pozzolanic Portland cement. But its companion coal bottom ash is not commonly used in any form. The current method of disposal of coal bottom ash in ponds poses risk to human health and to the environment. The hazardous constituents in coal bottom ash migrate and can contaminate ground water or surface water, and hence affect living organisms. In addition, there is danger of ash dyke spill and filling the surrounding area of pond with ash. River sand is the prime construction material and its excessive mining also results in unbalancing the ecological system. The natural resources of river sand are depleting gradually. As such, there is dire need to devise ways and means to cut down the growth of coal bottom ash accumulation and to save the environment. Thus the utilization of coal bottom ash in any form is the need of an hour for its safe disposal. The construction industry has enormous potential for the use of coal bottom ash as construction

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material. The productive use of coal bottom ash is the best way to alleviate the environmental problems and save the natural resources.

Coal bottom ash is usually a well-graded material and its particle size distribution is similar to that of river sand. Its particles have interlocking characteristics. Coal bottom ash is lighter and more brittle as compared to natural river sand. Coal bottom ash with low specific gravity has a porous texture that readily degrades under loading or compaction. Coal bottom ash derived from high sulphur coal and low rank coal is not very porous and is quite dense. Degree of pulverization of coal, firing temperature in the furnace and type of furnace affect the properties of coal bottom ash.

Appreciating the environmental problems, researchers in their studies have targeted coal bottom ash as fine aggregate in concrete. According to Cheriaf et al. (1999), coal bottom ash qualifies the requirements of European standard EN 450 for use in concrete. Topcu et al. (2014) observed that coal bottom ash can be used in production of durable geopolymer concrete without cement. A study carried out by Ghafoori and Bucholc (1997) revealed that durable concrete can be made with high-calcium coal bottom ash as fine aggregate. For fixed slump, they observed increase in water demand on use of coal bottom ash as replacement of sand in concrete. They also reported that concrete made with 50% sand and 50% coal bottom ash displayed compressive strength comparable to that of reference concrete and splitting tensile strength either equal or more than that of control concrete. Another study by Aggarwal et al. (2007) also demonstrated that though compressive strength of bottom ash concrete mixtures was lower than that of control concrete mixture at all the ages but the difference in compressive strength of bottom ash concrete mixtures and control concrete was less distinct after 28 d of curing period. Kim and Lee (2011) observed that strength properties of high strength concrete made with coal bottom ash as fine aggregate did not change significantly but there was considerable decrease in its modulus of elasticity. Andrade et al. (2009) also confirmed that inclusion of coal bottom ash in concrete resulted in reduction in modulus of elasticity. Published research literature indicates decrease in abrasion resistance on use of coal bottom ash as fine aggregate in concrete (Aramraks, 2006; Singh and Siddique, 2015). When fly ash was used as fine aggregate in concrete, compressive strength increased but abrasion resistance decreased (Siddique, 2003a,b). However, depth of wear of bottom ash concrete was less than specified in Indian standard BIS: 1237-2012 for heavy duty tiles. The use of water reducing admixtures have profound effect on compressive strength and splitting tensile strength of concrete made with coal bottom ash as partial replacement of sand (Ghafoori and Bucholc, 1997).

Sua-iam and Makul (2014) have rightly stated that the use of waste materials either as cement supplementary material or as sand replacement in concrete can result in cost savings and help in reducing the environmental problems. The major gain on use of coal bottom ash as fine aggregate in concrete is the reduction in the dead weight of structure in addition to alleviation of environmental hazards. Due to low specific gravity of coal bottom ash, concrete made with it has low density as compared to control concrete.

This research study was motivated by the ecological concerns over the disposal of coal bottom ash and scarcity of natural sources of river sand in the country. The ultimate objective of this research work was to study the workability and strength properties of concrete made with coal bottom ash as partial replacement of different sands having different fineness modulus. The present paper compares the strength properties of concrete made with coal bottom ash as replacement of two types of sands having fineness modulus of 1.97 and 2.58.

2. Experimental programme

2.1. Material

Coal bottom ash used in this study was collected from coal fired thermal power plant at Bathinda, Punjab (India). Specific gravity and water absorption of coal bottom ash and river sands were determined as per Indian standard BIS: 2389-1963 (Part III) an equivalent to ASTM C 128-93. Fineness modulus which is a numerical index of fineness giving some idea of the mean size of particles in the aggregate was obtained by sieving 500 g of river sand or coal bottom ash on a set of standard sieves from 4.75 mm to 150 μm and by adding the cumulative percentage of mass of material retained on all the sieves and dividing the total cumulative percentage by 100. Specific gravity, fineness modulus and water absorption of coal bottom ash were 1.39, 1.37 and 31.58%, respectively. The chemical analysis of coal bottom ash was performed using energy dispersive spectrometer (EDS). The chemical analysis shows that coal bottom ash is mainly composed of silicon dioxide (56.44%), aluminium oxide (29.24%) and iron oxide (8.44%) with small amounts of calcium oxide (0.75%), magnesium oxide (0.40%), sulphate (0.24%), sodium oxide (0.09%), potassium oxide (1.24%) etc. Loss on ignition of coal bottom ash was 0.89% and was less than 6% specified in ASTM C 618-03 for use of fly ash in Portland cement concrete. Total composition of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) present altogether in coal bottom ash was 94.21%. Coal bottom ash used in this study contains low-calcium oxide content (0.75%) and conforms to ASTM C 618-03 Type F ash. Fig. 1 shows the scanning electron micrograph of coal bottom ash. Scanning electron micrographs (SEM) shows that coal bottom ash particles have interlocking characteristics. Two types of sands having different fineness modulus used in control concretes were collected from two different sources. Sand having fineness modulus of 1.97 was obtained from Ghaghar River in Punjab (India) and another type of sand having fineness modulus of 2.58 was collected from Pathankot quarry, Punjab (India). Crushed stone aggregate with maximum size of 20 mm was collected from Pathankot quarry, Punjab (India). Specific gravity, fineness modulus and water absorption of coarse aggregate was 2.68, 6.28 and 0.38%, respectively. Particle sizes of coal bottom ash, Ghaghar sand and Pathankot quarry sand was determined as per Indian standard BIS: 2386-1963 (Part I) an equivalent to ASTM C 136-92 and the particle size distribution curves are illustrated in Fig. 2. Ordinary Portland cement of 43 grade conforming to BIS:8112-1989 an equivalent to ASTM C 150 Type I was used in this research work. Specific gravity

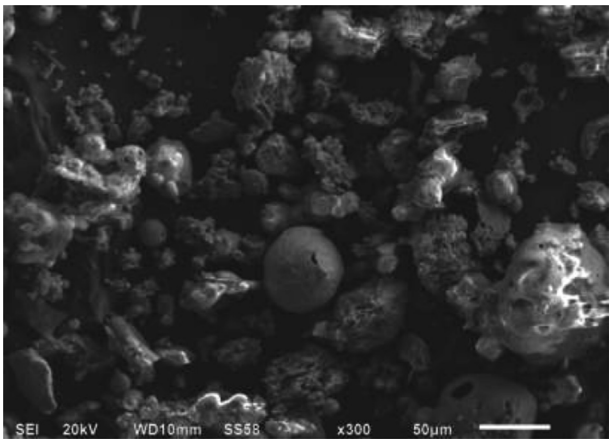

Fig. 1. SEM image of coal bottom ash.

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