Journal of Cleaner Production 91 (2015) 269–278

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Properties of concrete containing high volumes of coal bottom ash as fine aggregate

Malkit Singh [a,*], Rafat Siddique [b]

[a] Thapar University, Punjab 147004, India
[b] Department of Civil Engineering, Thapar University, Punjab 147004, India

ARTICLE INFO

Article history:
Received 5 September 2014
Received in revised form
5 December 2014
Accepted 6 December 2014
Available online 15 December 2014

Keywords:
Coal bottom ash
Compressive strength
Water absorption
Sorptivity
Pulse velocity
Abrasion resistance

ABSTRACT

Coal fired thermal plants in India produce about 131 million tons of coal ash, which comprises about 25 million tons of coal bottom ash. Utilization of coal bottom ash has environmental advantages also which are of great importance in the present context of sustainability of natural resources. The replacement of river sand with industrial by-products such as coal bottom ash in concrete can prove both technically and economically beneficial to the construction industry. In this study, laboratory tests were conducted to assess the possibility of the use of coal bottom ash as a substitute material of river sand in concrete. River sand was substituted with coal bottom ash by mass in concrete at 0, 30, 50, 75 and 100% replacement level. The test results show that 28 d compressive strength and pulse velocity through concrete were not affected on the use of coal bottom ash in concrete. Water absorption and initial rate of absorption of water by capillary action increased on incorporation of coal bottom ash in concrete manufacturing. However, the secondary rate of absorption of water was constant for all concrete mixtures. Water absorption varied between 4.68 and 5.56% for all concrete mixtures at curing period of 28 d. With increasing age, bottom ash concrete mixtures showed significant reduction in permeable pore space and water absorption. Abrasion resistance was measured in terms of average depth of wear. Bottom ash concrete mixtures displayed marginally lesser resistance to abrasion than control concrete. All the concrete mixtures showed decrease in the average depth of wear with increasing age, in other words increase in resistance to abrasion.

1. Introduction

Worldwide, concrete is the prime construction material used in the construction industry whereas cement, coarse aggregate and river sand are its main constituent materials. In India, particularly in Punjab, natural resources of river sand are dwindling gradually. At present, the scarcity of river sand had resulted in the abnormal rise in its price and consequently increased the cost of production of concrete. The construction industry is plagued due to scarcity and high cost of river sand. On the other hand, coal fired thermal power plants in the country have been accumulating tremendous volumes of coal bottom ash for decades. Deposits of coal bottom ash are becoming an environmental menace to the surrounding community.

Combustion of enormous volumes of coal at the thermal power plants results in production of coal bottom ash at a large scale. The coal ash content depends upon the non combustible matter present in coal. The rock detritus filled in the fissures of coal becomes separated from the coal during pulverization. In the furnace, carbon and other combustible matter burn, whereas the non-combustible matter results in coal ash. Swirling air carries the ash particles out of hot zone where it cools down. The flue gases carry away the finer and lighter ash particles. In the electrostatic precipitators installed prior to the stack, the ash particles are extracted from the flue gases. The coal ash obtained from the electrostatic precipitators is termed as fly ash. In the furnace, some particles of the ash accumulate on its walls and steam pipes. Due to the continuous accumulation of ash particles, clinkers are formed and when the clinkers become too heavy, they fall to the bottom of the furnace. In addition, the some coarser particles of ash, which are too heavy to remain in suspension with the flue gases, settle down at the base of the furnace. The coal ash, which settles at the bottom of the furnace, is termed as

* Corresponding author. Fax: +91 175 239 3005.
E-mail address: bhangal_ms@yahoo.co.in (R. Siddique).

http://dx.doi.org/10.1016/j.jclepro.2014.12.026
0959-6526/

coal bottom ash. Coal bottom ash constitutes about 20% of coal ash and the rest is fly ash.

Physical appearance of coal bottom ash resembles with natural river sand and its particle size varies from fine sand to fine gravel. The grading of coal bottom ash attracts the researchers to investigate its use as a substitute material of river sand in the production of concrete. A few research reports published so far show encouraging results on the use of coal bottom ash as a partial or total substitute material of fine aggregate in concrete production. Cheriaf et al. (1999) studied the pozzolanic property of coal bottom ash. They reported that strength activity indexes of coal bottom ash with Ordinary Portland cement at 28 d and 90 d of hydration were higher than that specified in European code EN 450 for pozzolanic material to be used in concrete. Their findings confirm that coal bottom ash has pozzolanic property and is suitable for use in concrete manufacturing. They also reported that coal bottom ash started reacting with portlandite at 14 d of hydration and after 90 d, consumption of portlandite was significant. Singh and Siddique (2013) in their review reported that coal bottom ash is a potential substitute material of sand in concrete. Topcu et al. (2014) observed that coal bottom ash can be used in production of durable geopolymer concrete without cement. Concrete made with low-calcium coal bottom ash as a replacement of river sand displayed strength properties comparable to that of conventional concrete (Singh and Siddique, 2014a). Concrete incorporating low-calcium coal bottom ash as fine aggregate exhibited better dimensional stability and displayed better resistance to chloride ion penetration as compared to the control concrete (Singh and Siddique, 2014b).

A limited research work is reported on the abrasion resistance, sorptivity and pulse velocity through concrete made with coal bottom ash as fine aggregate. The resistance to abrasion of concrete floors and paved surfaces is very important for their service life. Concrete pavement surfaces must be able to resist grinding from sand trapped beneath vehicle wheels. The key aspects which influence the resistance to abrasion of concrete are its compressive strength, aggregate properties and quality of surface finishes. The other factors which also affect the resistance to abrasion of concrete are the hardness of the aggregate and quality of bond between aggregate and paste. Further, the bond between aggregate and paste is influenced by the shape, texture, grading and soundness of aggregate.

The use of coal bottom ash as substitute of fine aggregate in concrete can affect water sorptivity, resistance to abrasion and pulse velocity of concrete. Concrete incorporating 50% high-calcium ($CaO = 22.50\%$) coal bottom ash as substitute of river sand displayed 13% higher abrasion resistance as compared to that of conventional concrete. However, abrasion resistance of bottom ash concrete incorporating of 100% coal bottom ash as fine aggregate was 40% lower than that of conventional concrete (Ghafoori and Bucholc, 1997). On use of water reducing admixture, abrasion resistance of bottom ash concrete improved significantly in comparison to that of bottom ash concrete without admixture and average depth of wear was lower than that of reference concrete (Ghafoori and Bucholc, 1996). High strength concrete incorporating up to 30% fly ash as a replacement of cement displayed abrasion resistance similar to that of reference concrete (Naik et al., 1995). Another study also revealed that the resistance to abrasion of concrete made with 35% fly ash was either equal to or greater than that of conventional concrete (Tikalsky et al., 1988). Water sorptivity is another important property of concrete and must be low for superior durability of the structure. Concretes with high water sorptivity are more susceptible to external chloride and sulphate attacks (McCarter et al., 1992). Sorptivity potential of concrete made with coal bottom ash as fine aggregate was higher than that of conventional concrete (Andrade et al., 2007). The sorptivity coefficient decreased with increase in compressive strength of concrete (Tasdemir, 2003). The curing age also affects the water sorptivity potentials of concrete. Water sorptivity of high volume fly ash concretes decreased significantly with increase in curing period (Chan and Ji, 1998). Baeza-Brotons et al. (2014) observed that concrete made with 10% sewage sludge ash as replacement of sand showed best performance in terms of water absorption and capillarity. Khatib and Mangat (1995) observed that the surface finish quality and position of surface of concrete subjected to test, greatly affect the sorptivity values. Siddique (2013) observed that sorptivity of self compacting concrete mixtures increased with the increase in quantity of coal bottom ash. Sorptivity of water varied between 0.055 and 0.145 $mm/\sqrt{min}$. Sorptivity of water is sensitive to the quality of the surface finish of concrete members. Sorptivity is an effective means to reveal the poor placing and finishing techniques in the field (McCarter, 1993).

Indian coals by virtue of their formation are different in some characteristics from European and American coals. Indian coals have high ash content up to 45%, low sulphur content in the range of 0.2–0.7% and low calorific value in the range of 2500–5000 kcal/kg (Visuvasam et al., 2005). Whereas coals in other parts of world have low ash content varying between 4 and 16%, high sulphur content up to 4% and high calorific value in the range of 5000–8000 kcal/kg. Extensive research on fly ash resulted in its use in large volumes in the manufacturing of concrete and cement all over the world. However, coal bottom ash has not been exhaustively examined for its uses. As such, its use is not common even in the developed countries like USA, UK etc. The present study was aimed to evaluate the feasibility of utilizing the Indian coal bottom ash as fine aggregates in concrete. In this study, properties such as compressive strength, pulse velocity, water absorption, sorptivity, and abrasion resistance of concrete made with coal bottom ash were evaluated and compared with those of control concrete.

2. Experimental programme

2.1. Materials

Ordinary Portland cement conforming to Indian standard BIS 8112-1989 grade 43 was used in this study. Properties of cement such as consistency, compressive strength and setting times were determined as per BIS: 4031-1988 and the test results are given in Table 1. Sand collected from Ghaghar River near Chandigarh, (India) was conforming to zone III as per Indian standard BIS 383-1970. Coal bottom ash (CBA) was obtained from Guru Hargobind Thermal Power Plant Bathinda, India. Crushed stone aggregate used in this study was obtained from quarry at Pathankot, Punjab, India. Physical properties of coal bottom ash, river sand and coarse aggregate are given in Table 2. The particles of coal bottom ash are porous. Scanning Electron Micrograph presented in Fig. 1 shows the presence of voids in large number in coal bottom ash particles. Large amount of water gets absorbed in these voids. Bai et al. (2005) also observed water absorption of coal bottom ash as 30.4%. The

Table 1
Properties of cement.

Fineness (m^2/kg)	278.6
Initial setting time (min)	125
Final setting time (min)	175
Compressive strength (MPa)	
3 d	32.0
7 d	40.3
28 d	51.5
Consistency (%)	28
Specific gravity	3.13