Advances in Concrete Construction, *Vol. 4, No. 4 (2016) 231-242*
DOI: https://doi.org/10.12989/acc.2016.4.4.231

Performance of bricks and brick masonry prism made using coal fly ash and coal bottom ash

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(Received July 18, 2016, Revised December 28, 2016, Accepted January 3, 2017)

Abstract. The major problem of a coal combustion-based power plant is that it creates large quantity of solid wastes. So, to achieve the gainful use of waste materials and to avoid other environmental problems, this study was undertaken. The quantity of coal ash by-products, particularly coal fly ash and coal bottom ash has been increasing from the coal power plants around the world. The other objective of this study was to explore the possibility of utilization of coal ash in the production of ash bricks. In 15 different mixes, Mix Designation M-1 to M-15, the varying percentages of lime and gypsum were used and sand was replaced with coal bottom ash. Further, it has been noticed that the water absorption and compressive strength of mix M-15 is 13.36% and 7.85 MPa which is better than the conventional bricks. The test results of this investigation show that the prism strength of coal ash masonry prisms was more than that of the conventional bricks.

Keywords: coal fly ash; coal bottom ash; sand; lime; gypsum; compressive strength; water absorption; masonry prism

1. Introduction

Housing is essential necessity for mankind's survival. The most basic building material for construction of houses is the usual conventional bricks. Conventional bricks are being used extensively almost throughout India and are perhaps the most important building material. All the bricks kilns in India depend on good quality of clay is available from agricultural fields. The continuous removal of top soil for production of conventional bricks creates environmental problems. Moreover, clay bricks available in certain regions are poor in quality and costly. The manufacturing of conventional clay bricks involves the consumption of large amount of clay and significant quantity of fuel.

Punjab state council of science and technology (2016) estimated annual coal consumption in the bricks industry as 24 million tonnes. Coal consumption by the brick industry is approximately 8% of the total coal consumption. China is the largest producer of bricks in world and India stands

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http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2287-5301 (Print), 2287-531X (Online)

second in this race. In last 5 years India has shown 8% growth economically and proved to be largest developing country. There is an increase in brick production by 5-10% annually as per 2009 estimates due to housing, various developmental sectors and infrastructure. There is an estimate of 1,45,000 registered and unregistered brick kilns with production of more than 236 billion bricks.

American Coal Ash Association (2013) concluded the production of fly ash and bottom ash is 53.40 million metric tonnes and 14.50 million tonnes respectively. The consumption of fly ash is 23.32 million tonnes (43.67 % of total production of bottom ash) and 5.60 for bottom ash (39.02% of total production of bottom ash). Duggal (2012) investigated fly ash or pulverized fuel ash as the residue from the combustion of pulverized coal collected by mechanical or electrostatic separators from the flue gases of power plants. It constitutes about 75% of the total ashes produced. Naganathan *et al.* (2015) investigated use of fly ash and bottom ash use in bricks manufacturing that will lead to bulk consumption and hence contribute to sustainable development.

Vidhya *et al.* (2013) studied the utilization of fly ash in bricks. The fly ash can be effectively used for manufacture of bricks using fly-ash, lime, sand and Gypsum. The useful proportion found was 25: 4: 3.33: 1. Akhtar *et al.* (2011) observed the effect of 'C' category fly ash with cement and sand in different proportion and concluded that treated fly ash is superior in strength and the best result is found when the brick is made of 50% of fly ash and 25% admixture of sand and 10% weight of lime stone dust. Mistry *et al.* (2011) reported that fly ash bricks masonry save 28% cost as compared to conventional brick masonry. The masonry work with new technology Rat-Trap bond in ash brick saves 33% cost as compared to common bricks. Vidhya *et al.* (2013) examined the compressive strength of bricks is increased with the increase in lime contents. Weight density of bricks reduced with increase in pond ash percentages. The water absorption value of bricks decreased with the increase in pond ash. The cost is reduced up to 20% than the conventional clay bricks manufacturing.

Naganathan *et al.* (2012) studied bricks using fly ash, bottom ash and cement concluded that the strength of bricks increases with increase in fly ash. Banu *et al.* (2013) concluded that at the optimum composition 55% of fly ash with sand, lime and gypsum, bricks exhibited no shrinkage and water absorption observed as 11.58%. If brick forming pressure is applied in bricks manufacturing then brick will show increases in compressive strength, increases in unit weight and Initial Rate of Absorption (IRA). Naganathan *et al.* (2015) examined that increase in fly ash reduced the water absorption and stated that the optimum ratio is 1:1:0.45 (bottom ash : fly ash : cement) for better performance.

Bai *et al.* (2005) and Shi-Cong *et al.* (2009) studied furnace bottom ash as a waste material from coal-fired thermal power plants. It usually has no pozzolanic property. However, its particle distribution is similar to that of sand, makes it attractive to be used as a sand replacement material in concrete. Both the drying and shrinkage increase with the increase of the furnace bottom ash sand content beyond 30 % replacement level.

Rajgor *et al.* (2013), Gawatre *et al.* (2014) and Varshney *et al.* (2014) observed the effect of stone waste in fly ash bricks and concluded that with the increase of stone dust compressive strength increases, water absorption decreases. Sumathi *et al.* (2014) concluded that the optimized compressive strength obtained as 7.91 MPa at optimal mix percentage (fly ash-15%, lime-30%, gypsum-2% & quarry dust-53%).

Singh *et al.* (2014) stated that at fixed cement ratio, workability and loss of water from bleeding decrease by using bottom ash as a replacement of sand in the concrete. The compressive strength of bottom ash concrete is better than that of conventional concrete. The incorporation of bottom ash in the concrete improved the splitting tensile strength whereas modulus of elasticity decreased.

Dar *et al.* (2015) have investigated the properties of non-conventional bricks using fly ash, lime, gypsum and quarry dust. Ash Bricks were found to be sufficiently hard, better ringing sound and homogenous structure without any defects as compared to conventional bricks. The efflorescence of all bricks tested were found to be slight as grey deposits were less than 10% on surface of the bricks which is almost same as that in the normal bricks. Singh *et al.* (2015) observed that due to incorporation of coal bottom ash as a partial replacement of fine aggregate the compressive strength of concrete made using bottom ash improved at a faster rate compared to that of control concrete with age. Bottom ash concrete and control concrete showed almost identical performance under external sulphate and acid attack.

Saini and Ashish (2015), Mukharjee and Barai (2015), Prusty *et al.* (2015) and Saha and Rajasekaran (2016) analysed recycled coarse aggregates for production of concrete. Ashish *et al.* (2011), Kumar *et al.* (2014), Thomas and Harilal (2014), Kumar *et al.* (2015c), Sunil *et al.* (2015) and Chore and Joshi (2015) examined the use of fly ash in construction and building materials. Singh (2011), Tang *et al.* (2015) and Ashish *et al.* (2016a) examined use of GGBFS as replacement of cement materials. Güneyisi *et al.* (2014) and Verma and Ashish (2014) studied waste rubber tyre as substitution of aggregate in concrete. Parande (2013) investigated industrial by-product for high performance concrete. Ganesan (2013), Patil *et al.* (2014) and Shaikh (2014) investigated geopolymer concrete for its sustainable growth. Wani *et al.* (2015), Kumar *et al.* (2015a), Kumar *et al.* (2015b), Ashish *et al.* (2016b) and Ashish *et al.* (2016c) investigated different waste materials for sustainable growth in of construction development.

Shakir *et al.* (2013) investigated the use of different wastes like fly ash, bottom ash for use in construction industry and the most useful was manufacturing of bricks with the use of wastes. In this study properties of bricks made using fly ash and bottom ash were calculated. It will lead to consumption of waste materials and shall add to sustainable growth.

2. Materials used

2.1 Fine aggregate

In this study, locally procured natural sand was used and it conformed to grading Zone-II as per BIS: 383 (1970). The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the lumps of clay and other foreign material. The Specific gravity of sand used was 2.63.

2.2 Coal fly ash

Coal fly ash was procured from Guru Nanak Dev Thermal Power plant (GNDTP), Bathinda, India. To assess the properties of coal fly ash, the properties based on laboratory tests conducted by Central Soil and Material Research Station, New Delhi and CBRI, Roorkee, India were used. The Chemical and Physical properties are shown in Tables 1-2.

2.3 Coal bottom ash

Singh and Siddique (2014), the coal bottom ash was collected from Guru Har Gobind Thermal Power Plant, Lehra Mohabat, Punjab, India. Guru Har Gobind Thermal Power Plant produced

Table 1 Chemical properties of coal ash

Chemical component	Materials	
	Coal fly ash	Coal bottom ash
SiO2	56.32	47.53
Al_2O3	30.87	20.69
Fe_2O3	4.94	0.76
K_2O	-	2.55
CaO	1.58	4.17
TiO_2	-	1.30
SO_3	-	1.00
Na_2O	-	0.33
MgO	0.70	0.82
Loss of Ignition (LOI)	4.52	1.00

Table 2 Physical properties of coal ash

Properties	Coal fly ash	Coal bottom ash
Bulk density in kg/m^3	1000	-
Surface area in m^2/kg	468	-
Specific gravity	2.03	1.39
Lime reactivity in MPa	5.98	-
Water absorption by mass (%)	-	31.58
Fineness modulus	-	1.37

Table 3 Various mix proportions of coal ash bricks

Mix ID	Fly ash	Bottom ash	Sand	Lime	Gypsum
M-1	1	0.00	1	0.05	0.05
M-2	1	0.00	1	0.10	0.05
M-3	1	0.00	1	0.15	0.05
M-4	1	0.25	0.75	0.05	0.05
M-5	1	0.25	0.75	0.10	0.05
M-6	1	0.25	0.75	0.15	0.05
M-7	1	0.50	0.50	0.05	0.05
M-8	1	0.50	0.50	0.10	0.05
M-9	1	0.50	0.50	0.15	0.05
M-10	1	0.75	0.25	0.05	0.05
M-11	1	0.75	0.25	0.10	0.05
M-12	1	0.75	0.25	0.15	0.05
M-13	1	1	0.00	0.05	0.05
M-14	1	1	0.00	0.10	0.05
M-15	1	1	0.0	0.15	0.05

about 0.16 million tons of coal bottom ash annually and is disposed off in ponds spread over about 450 acres. The coal bottom ash was screened to remove the oversized particles and the material

passing through 4.75 mm sieve was used in manufacturing of ash bricks. The chemical and physical properties of coal bottom ash used in this research are given in Tables 1-2. The chemical analysis shows that coal bottom ash is mainly composed of silica and alumina. The particles having complicated shape and surface texture were also observed in the coal bottom ash.

2.4 Gypsum

Hydrated Calcium sulphate is called Gypsum ($CaSO_4{:}2H_2O$). It has a specific gravity of 2.31 grams per cubic centimeter. The density of gypsum powder is 2.8 to 3 grams per cubic centimeter. Reddy and Gaurav (2011) Gypsum is an additive which accelerates the rate of strength gain. It binds particles, results in negligible shrinkage. Chemical or mineral gypsum can be used for making ash bricks. The gypsum used was free from lumps and having purity of about 60%.

Banu *et al*. (2013) Gypsum is a non-hydraulic binder occurring naturally as a soft crystalline rock or sand. Gypsum have a valuable properties like small bulk density, incombustibility, good sound absorbing capacity, good fire resistance, rapid drying and hardening with negligible shrinkage, superior surface finish etc.

2.5 Hydrated lime

Hydrated Lime is used for ash brick making should conform to (class ‘C’) grade as specified in BIS: 712 (1984). It prevents shrinkage of raw bricks on drying. The product obtained by slaking of quick lime is known as slaked or hydrated lime or Fat Lime.

$$CaO \text{ (Quick lime)} + H_2O \text{ Slaking} \longrightarrow Ca(OH)_2 \text{ (Hydrated Lime)} + \text{Heat}$$

The CaO purity in the lime should not be less than 85% which can be ascertained by testing or by taking test certificate from the lime suppliers. The lime should be stored in bags or silos or in covered bins as it has tendency to react with CO_2 present in the air in presence of moisture and produces $CaCO_3$ which does not have binding properties and spoils the quality.

3. Experimental program

The effect of using varying percentages of lime, coal fly ash and coal bottom ash was investigated in present study. Comparison of the results of prism strength of masonry walls using ash bricks and conventional bricks was also made. Ash bricks as per various mixes (M-1 to M-15) have been cast. The details of various mix proportions have been given in Table 3.

3.1 Casting of ash bricks

In batch mixing all the materials considered in present study were used in making ash bricks i.e., sand, lime, gypsum and fly ash were transported to the roller mixer in required quantities where mixing of all the materials take place. In case, hydrated lime and gypsum were used for making ash bricks, the required quantity of sand, fly ash, bottom ash, lime and gypsum were initially dry mixed and required quantity of water was added to get homogenous mix. The homogenous mix was fed into vibro/hydraulic press manually or through conveyer belt to mould it into brick shape. The moulded bricks were kept in wooden/steel pallets and taken to stacking area

Table 4 Specification for cement brick and masonry and age of testing

Properties	Standard	Category	Age of testing	Exposure period
Sand	BIS 383:1970	Sand	-	-
Compressive strength	BIS 3495 (P-1):1992	Brick	28 days	-
Water absorption	BIS 3495 (P-II):1992	Brick	-	24 hours
Crushing strength of prism	BIS 1905:1987	Brick masonry	28 days	-

Table 5 Test results for water absorption of various mixes of coal ash bricks

Mix ID	Water absorption (%)
M-1	13.29
M-2	13.21
M-3	12.63
M-4	14.57
M-5	15.42
M-6	14.09
M-7	17.17
M-8	16.69
M-9	15.31
M-10	18.83
M-11	18.07
M-12	14.32
M-13	15.59
M-14	15.37
M-15	13.36
Conventional bricks	14.58

for air drying. After bricks were prepared in automatic brick making machine the green bricks were air dried up under sun for 1 to 2 days. The dried up bricks were stacked and subjected for water spray curing once or twice a day for 7 to 21 days on ambience.

3.2 Testing methods

In this study, coal ash was used in bricks. The details of relevant tests conducted are shown in Table 4.

4. Results and discussions

4.1 Water absorption

The water absorption test for coal ash bricks and conventional bricks was carried. The results obtained are shown in Table 5 for ash bricks and conventional bricks.

Table 6 Test results for crushing strength of various mixes of coal ash bricks

Mix ID	Crushing strength (MPa)
M-1	2.66
M-2	3.48
M-3	5.91
M-4	1.78
M-5	3.35
M-6	3.39
M-7	1.51
M-8	2.28
M-9	3.41
M-10	3.42
M-11	4.67
M-12	7.08
M-13	4.48
M-14	5.49
M-15	7.85
Conventional bricks	7.81

The water absorption for the mixes (M-1 to M-15) ranged between 12.63% to 18.83%. Most of ash bricks groups (M-1 to M-15) except brick groups M-1 to M-4, M-6, M-12 and M-15 exhibited water absorption less than that shown by conventional bricks. As the quantity of coal bottom ash increases water absorption decreases. The increase in the proportion of sand in the mix also decreases the water absorption.

Table 5 depicts, the average water absorbed by the conventional brick is 14.58% and average water absorbed by the ash bricks (M-15) is 13.36%. Benson *et al.* (2011) clearly shows that bottom ash is not a water absorber because percentage of water absorption for bottom ash is 0.3-6.1%. Naganathan *et al.* (2012) fly ash increases water absorption in mixes as it is water absorbent material.

4.2 Crushing strength test

The crushing strength test results for coal ash bricks and conventional bricks are shown in the Table 6. For the bricks manufactured using coal bottom ash and lime the highest compressive strength of mixes was (M-15) observed to be 7.85 MPa. The compressive strength of the conventional brick was found to be 7.81 MPa. For this mix, the increase in strength is due to the increase in lime content which acts as a binder and improves the compressive strength. The increase of coal bottom ash lime and gypsum content in this mix resulted in increased chemical reaction and hence increase in the compressive strength.

Table 6 depicts, the average crushing strength of conventional bricks is 7.81 MPa and that for ash bricks (M-15) is 7.85 MPa. According to Ghafoori and Bucholc (1996) Increase in compressive strength was achieved with the increase in bottom and binder content due to increase in chemical reaction. Ghafoori and Bucholc (1997), Singh and Siddique (2015) the increase in coal

(a) Brick prism of coal ash bricks before loading (b) Brick prism of coal ash after loading

Fig. 1 Brick masonry prism of coal ash bricks

Table 7 Masonry prism test results of conventional bricks and ash bricks made in different cement mortar

Type of bricks	Average crushing strength (MPa)	% Increase of average crushing strength
Cement sand mortar (1:3)		
Conventional bricks	1.62	-
Ash bricks	1.84	11.96
Cement sand mortar (1:4)		
Conventional bricks	1.47	-
Ash bricks	1.58	6.97
Cement sand mortar (1:5)		
Conventional bricks	1.40	-
Ash bricks	1.56	10.25

bottom ash content increased strength of mix due to high calcium content in coal ash.

4.3 Masonry prism test

The crushing strength test for conventional bricks and ash bricks was carried out as per BIS: 1905 (1987) and results obtained were compared in Table 7. Masonry prism testing setup is shown in Fig. 1.

As shown in the Table 7, for cement mortar (1:3) the crushing strength of conventional bricks is noticed as 1.62 MPa and that for ash bricks is 1.84 MPa. Therefore, there is 11.96% increase in the crushing strength by prism test for ash bricks as compared to conventional bricks. For cement mortar (1:4), the crushing strength of conventional bricks is noticed as 1.47 MPa and that for ash bricks is 1.58 MPa. Therefore, there is 6.97% increase in the crushing strength by prism test for ash bricks as compared to conventional bricks. For cement mortar (1:5), the crushing strength of conventional bricks is noticed as 1.40 MPa and that for ash bricks is 1.56 MPa. Therefore, there is

Table 8 Crack width and load applied for coal ash brick masonry prism in different mortar

Type of bricks	Crack	Load applied (kN)	Crack width (mm)	Remarks
For coal ash bricks				
Cement sand mortar (1:3)	1st	176	1.5	Cracks appeared in the brick joints as well as in bricks
	2nd	202	5.5	
Cement sand mortar (1:4)	1st	152	1.5	Cracks appeared in the brick joints as well as in bricks, however, more cracks were seen in the brick joints
	2nd	184	4	
Cement sand mortar (1:5)	1st	58	2.5	Cracks appeared in the brick joints
	2nd	168	8	
For conventional bricks				
Cement sand mortar (1:3)	1st	168	1.5	Cracks appeared in the brick
	2nd	193	5.5	
Cement sand mortar (1:4)	1st	125	1.5	Cracks appeared in the brick joints as well as in bricks however more cracks were seen in the brick
	2nd	166	4	
Cement sand mortar (1:5)	1st	60	1.5	Cracks appeared in the brick joints as well as in bricks
	2nd	153	8	

10.25% increase in the crushing strength by prism test for ash bricks as compared to conventional bricks.

The maximum crack width was observed to be 2.5 mm and 8 mm on the application a load of 58 kN and 168 kN respectively, during the testing of masonry prisms made using coal ash bricks in cement and sand mortar (1:5) as shown in the Table 8. For other mix proportions the values have been tabulated above. The position of cracks were in agreement with observations of Dar *et al.* (2015) who opined that because of presence of micro fine particles of fly ash the mortar presented smooth surface and resulting in weakening of joints of brick and mortar in case of ash bricks and cracks appeared in joints in all the three mixes.

5. Conclusions

On the basis of results obtained in present study, the following conclusions can be drawn.

• Compressive strength of best ash brick M-15 was found to be 7.85 MPa, which is marginally higher than the strength of conventional brick.

• Water absorption for M-15 ash bricks was found to be 13.36%.

• For rich cement mortar the bricks failed whereas for leaner mortar the masonry failed at joint.

• With the increase in lime and coal bottom ash content in the mix, strength increases and the water absorption decreases.

• The structure of the ash bricks was found to be compact, homogeneous and free from any defects like holes, lumps etc. as compared to conventional bricks.

Therefore, it is recommended that bricks of group M-15 can be used commercially as their performance in terms of compressive strength and water absorption was found to be better than conventional bricks. Further this will also solve disposal of ash problem, which otherwise poses a hazard.

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