Chapter

Coalash as Sustainable Material for Low Energy Building

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Abstract

Sand, which is a naturally occurring soft mineral ranks second after water, as far as consumption is concerned globally. Due to rapid infrastructural development worldwide, particularly in Asian region, the rate of natural formation of sand has been found to be outpaced by rate of consumption, causing greater ecological imbalances. Coalash, an industrial waste from thermal power plants are polluting in nature, and legacy ash in huge proportion without proper utilization is posing a serious threat to the environment. It was ideated to replace sand by coalash in concrete and mortar mix, and to evaluate the physical and thermal properties for its suitability in low energy building construction. Without compromising strength criteria, thermal transmittance value is found to be reduced up to considerable extent, which resulted lesser cooling requirement with added economic benefit. This medium technology application could be one of the economic pathway towards Near Zero Building Construction.

Keywords: sand, coal ash, energy, envelop, building

1. Introduction

Coal, being the largest source of power worldwide, contributes maximum in respect of global CO_2 Emission. More than 33% of global electricity was produced by 2100 GW cumulative capacity coal based thermal power plants in 2020. China, United States and India are ranked as top three nations for coal combustion linked electricity production [1]. This being fossil fuel, and linked to CO_2 emission, worldwide movement has been started to tone down its usage. The ash produced as a fallout of coal burning is classified into fly ash and bottom ash. It is considered that for every 4 tonnes of coal burnt, approximately one ton of coal ash is produced [2]. The ash content actually depends on type of coal burnt, which is classified as anthracite, bituminous, sub-bituminous and lignite. But, the legacy ash already stored in various ash ponds of thermal power plants is huge and continuously affecting the environment by contaminating surrounding air and soil. In spite of various efforts undertaken by authorities, 100% ash utilization could not be made possible. On the other hand, sand, the natural soft mineral is continuously depleted due to mindless sand mining mainly for infrastructure related developmental requirements. In fact, rate of formation of sand is getting outpaced by rate of extraction, thus creating a serious environmental imbalances. Considering the rapid growth in urbanization and particularly huge demand in building sector, the energy consumption by building sector alone is enormous. Overall, buildings accounted for 36 per cent of global energy demand and 37 per cent of energy-related CO_2 emissions in 2020. Since the signing of the Paris Agreement in 2015, greenhouse gas emissions from the buildings and construction sector had peaked in 2019 and subsequently fallen to 2007 levels in 2020 mostly due to the COVID-19 pandemic [3]. Despite the expected rebound in emissions in 2021 being moderated by continued power sector de-carbonization, buildings remain off track to achieve carbon neutrality by 2050. To meet this target, all new buildings and 20% of the existing building stock would need to be zero-carbon-ready as soon as 2030 [4]. Buildings consume energy at different levels of the life cycle. The fastest-increasing end uses of energy in buildings are for space cooling, appliances and electric plug-loads, which contribute buildings sector electricity demand growth. Researchers observed that operational energy requirement by buildings occupy lion's share (around 80%) and rest is shared by material embodied energy including transportation, construction etc. related energy consumptions. It was also observed that a normal residential purpose use building and an office purpose use building consume on an average 275 kWh/m^2/year, and 400 kWh/m^2/year respectively [5]. Though these figures depend on many factors like climatic condition of the area, material choice, orientation / layout etc. the overall life-cycle energy figure can be optimized by appropriate planning and design. Among all the building components, envelop influences in deciding the energy ingress or egress to and from the building core. Such flow of energy ultimately determines the operational energy requirement for the particular building, depending on its functionality. Therefore the design of envelop with appropriate material property can contribute significantly from energy efficiency point of view. This research topic presents an approach in passive design of building envelop by selecting waste based abundantly available material, which might evolve into less heat conducting concrete and mortar. Thus, coal ash substitution in building construction industry address the issues of effective thermal power plant waste utilization, arresting rapid depletion of sand and improvement in building energy efficiency together.

2. Building envelop and constituent materials

2.1 Conventional materials

The building envelop influences heat conduction through roof, wall, fenestrations and determine the quantum of sensible cooling/heating load requirement to balance comfort condition. As per the report, published by International Energy Agency in 2013, the demand for space air-conditioning is estimated to rise three fold between 2010 and 2050 on account of more numbers of hot days [6]. To restrict more heat entry inside the building, insulating materials are put to use. The conventional materials, which are used for this purpose are mostly by-products of fossil fuel oil industries, and the cost and embodied energy content of those are very high, besides being hazardous at the end of life disposal scenario. Choice of materials for energy efficient envelop construction should cater to the issues of durability, environmental sustainability, local sourcing of materials to reduce transportation related emission etc. Concrete is an integral composite material in modern building construction with considerable carbon footprint, due to one of its constituent with high embodied energy content, which is cement. It has been observed that Ordinary Portland Cement (OPC) contains the highest Global Warming Potential (GWP), Photochemical Ozone

Creation Potential (POCP) and Abiotic Depletion Potential (ADP) [7]. Paints with high reflection parameter on roof and other types of insulating materials are included in energy efficient building design. The manufacturing energy and GWP of normally used such materials are on the higher side [8]. Bergey had presented in a Symposia about the comparative study of various commercially available insulating materials, among which XPS was observed to be with highest embodied global warming potential (GWP) [9]. High albedo coating with cool roof feature contain embodied energy to the tune of 23 MJ/m^2 of roof surface [10].

The walls in a building are conventionally made up of bricks, joined with mortar and covered by plaster on both sides, topped with paint and other finishing. The materials used for mortar and plaster are cement and sand of different proportions and grade (MM3/MM5 etc.) [11].

Since, major carbon intensive component in concrete is cement, sustainable concrete mixes had been adopted for this work with the inclusion of Portland Pozzolana Cement (PPC) (30% fly ash blended), stone aggregate, sand, water and fly ash /bottom ash / marble dust / lime dust.

2.2 Coal ash as constituent material in envelop construction

Coal ash is basically a combination of lighter fly ash (75–80%) and coarser bottom ash particles, produced out of coal combustion in thermal power plants with zero embodied energy content. Depending upon its CaO percentage in the composition, it is classified as Class C (with some cementatious property) or Class F (with pozzolanic property). Globally, 100% utilization of coal ash from all the thermal power plants has not become possible till date. Cumulative accumulation of the un-utilized coal ash each year in ash dykes are creating groundwater contamination, air pollution etc. On the other hand, due to the rapid growth in global infrastructure sector, unprecedented rate and pace of sand mining from river bed is threatening the ecological balance enormously. Various researchers have explored the suitability of this industrial waste, which is coal ash in building construction, as a constituent material of concrete and mortar. To name a few, Higgins had compared one tone of concrete made of ordinary Portland cement as main constituent and the same quantity of concrete with Portland pozzolana cement with 30% flyash blend. It was observed that 17% less CO_2 emission to the atmosphere, 14% less primary energy requirement and 4% less mineral extraction resulted with such substitution [12]. The earlier works related to utilization of coal bottom ash in concrete have been studied. OPC, sand, bottom ash and stone aggregate as the concrete mix constituents were used. The results revealed that 10–30% replacement of sand by bottom ash did not adversely impact the desired strength gain in the concrete, barring some losses in workability and flexural strength parameters [13–19]. Another group of Researchers investigated about the suitability of fly ash and bottom ash as replacement material of cement and normal river sand utilized in concrete making. The compressive strength values at 28 days after casting were noted to be without change in comparison with conventional concrete mix ingredients. The workability parameter of the concrete mix was noted to be stiff, but at a longer maturity period, strength increased considerably. Toxicity parameters and durability aspects including leaching procedure, sulfate and acid attack and elevated temperature effects on concrete blended with coal ash as substitute to cement and sand were also studied, and the test results did not reflect any adverse impact, and as such considered to be used as clean construction material [20, 21]. Other researchers explored about the usage of fly ash as fine aggregate in masonry mortar and found that up to a considerable replacement ratio, the fly ash blended mortar can be used [22]. Soheil Oruji, Nicholas A. Brake and others tried to see if the finely ground bottom ash can act as an alternative material to cement in mortar preparation. The fineness effect on workability as well as, on setting time were studied. Improvement in micro-structure of cement mortar and increase in the strength parameter of such product was observed [23]. Kim had experimented with sieved and ground coal bottom ash in high strength cement mortar. The ground bottom ash was found to increase the workability and compressive strength values compared to the equivalent mortar made of cement and fly ash [24]. Shahidan et al. had studied the physical and chemical properties of coal bottom ash, as a replacement material for sand. The gradation of particles in bottom ash and sand showed some similarity, and overall, bottom ash is recommended favorably as a replacement material to sand [25]. Abbas et al. had also studied the effect on cement and sand by limestone dust and bottom ash partially respectively. For a number of mixes, sand substitution by bottom ash were done in various replacement ratios, and limestone dust replacement ratio with cement was maintained constant at 5% ratio. Water-cement ratio was same for all mixes. Increase in strength was found consistent up to 30% sand substitution and 5% cement substitution [26]. Ghosh et al. had experimented with coal bottom ash and fly ash separately as sand substitute in different concrete mix proportions. It was observed that with increasing percentage of replacement, thermal resistance parameter increased but the strength parameters decreased. Up to 40% replacement, the blended concrete exhibited desired strength with considerable percentage of decreased thermal conductivity value [27]. In another set of experiments, Ghosh et al. had further observed the effect of coal bottom ash and fly ash separately on masonry mortar of different proportions. The sand in the mortar was replaced by bottom ash and fly ash (separately) in steps of 10% up to 100%. The masonry mortar minimum strength criteria was observed to be fulfilled up to 100% replacement ratio, and specific mortar grade requirement was fulfilled up to 60% replacement with an astounding result of lower thermal conductivity [28].

3. Method

3.1 Materials and characterizations

In the research work, PPC, river sand, stone aggregate of 10 mm down size, potable quality water and coal ash were used. For material characterization, quantitative chemical analysis (for cement, sand, fly ash and bottom ash), X-Ray Diffractogram (XRD) (for cement, sand, fly ash and bottom ash), sieve analysis (for sand, bottom ash and stone aggregate), particle size analysis (for fly ash), density test (for cement, sand, fly ash, bottom ash and aggregate), surface area determination (cement, fly ash and bottom ash) and Finite Element Scanning Electron Microscopy (FESEM) (for sand, fly ash and bottom ash) were carried out as per standard testing protocol. Chemical analysis results are tabulated and XRD and FESEM images (of fly ash and bottom ash) are shown below (**Figures 1**–**4** and **Table 1**):

Grading curve obtained by sieve analysis for bottom ash sample and particle size curve of fly ash sample are shown below (**Figures 5** and **6**):

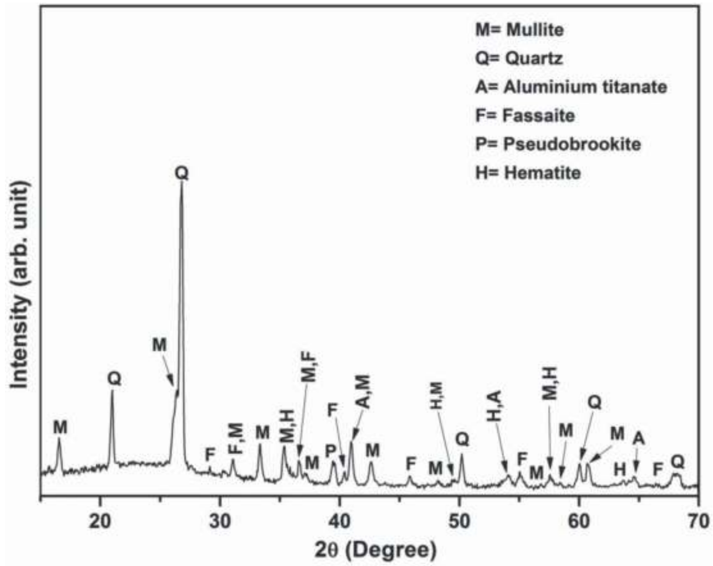

Figure 1.
XRD of fly ash sample.

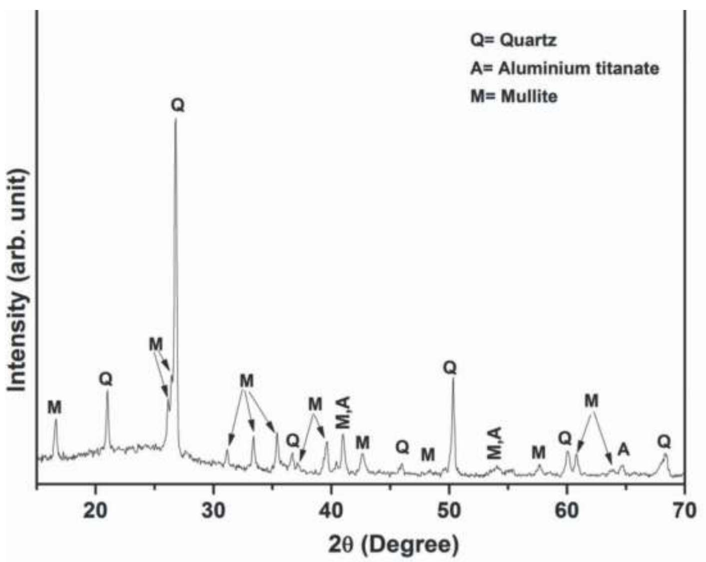

Figure 2.
XRD of bottom ash sample.

3.2 Experimental programme

The main objective of the experimental investigation is to ascertain the physical strength of the Concrete and Mortar mixes and finding out the thermal conductivity value of such mixes. The different mixes were designed with replacement of natural mineral by Coal ash and the changes thereof with respect to the physical and thermal properties.

Concrete mix design on the basis of basic ingredient material properties and fixing of proportions as per IS 456: 2000 [30], IS 10262: 2009 [31] and SP 23: 1982 [32] code provisions. Mortar mix selection as per relevant IS 2250: 1981 [11] code provisions.

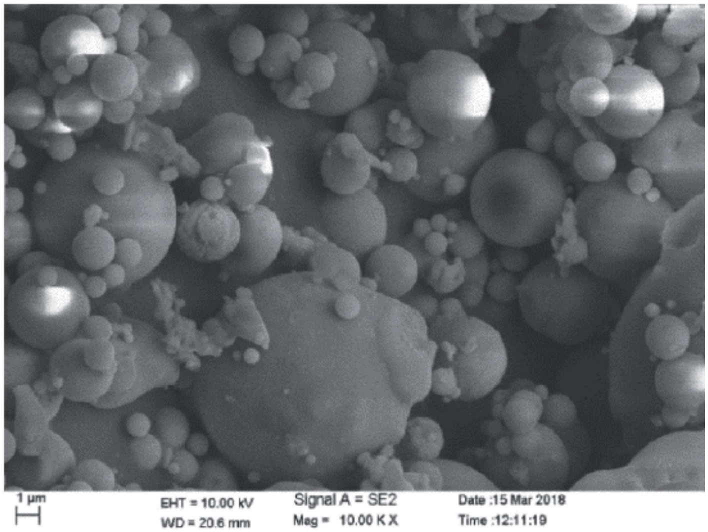

Figure 3.
FESEM of flyash at 10000X.

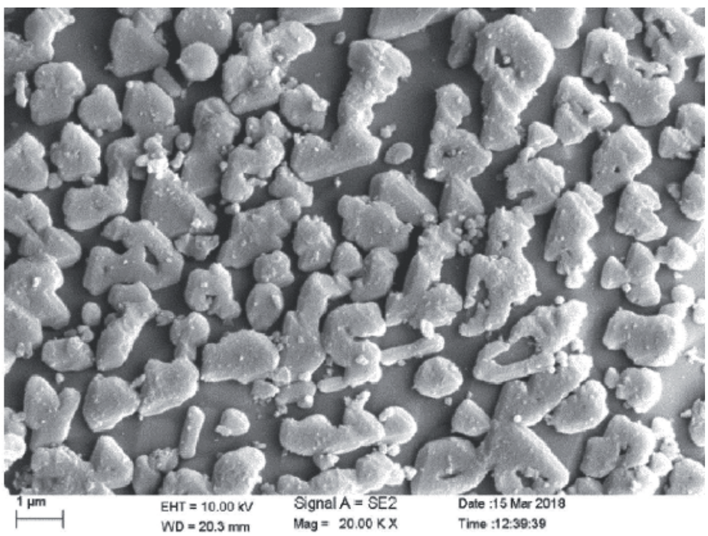

Figure 4.
FESEM of bottom ash at 20000X.

Universal testing machine for compressive strength determination and apparent porosity and bulk density test apparatus for concrete and mortar samples were utilized. For thermal conductivity determination of concrete and mortar samples, hot disk TPS 2500S instrument (working on Transient Plane Source method by following ISO 22007-2) was used and for overall heat transfer coefficient determination (U-value), guarded hot box method was adopted. Altogether around 200 samples were prepared and tested. Some of the concrete and mortar mixes are tabulated as below (**Tables 2–5**):

3.2.1 Guarded hot box test set-up to measure overall heat transfer co-efficient (U value)

A Guarded Hot Box test setup was designed and developed in School of Energy Studies, Jadavpur University, India. The setup was constructed following standard

Parameters tested	Requirement as per IS 3812	Test data of flyash used	Test data of bottom ash used
Silicon-di-oxide (SiO_2) + aluminum oxide (Al_2O_3) + iron oxide (Fe_2O_3) (%) by mass, Min.	70.00	51.38 + 33.12 + 6.87 = 91.37	60.71 + 25.86 + 6.81 = 93.38
Silicon di-oxide (SiO_2) (%) by mass, Min.	35.00	51.38	60.71
Magnesium oxide (MgO) (%)by mass, Max.	5.00	0.47	0.63
Total sulfur as sulfur tri-oxide (SiO_3) (%) by mass, Max.	2.75	0.09	0.15
Available alkalis as sodium oxide (Na_2O) % by mass, Max.	1.50	0.72	0.38
Loss on ignition, % by mass, Max.	12.00	1.80	0.92

Table 1.
Chemical composition of fly ash and bottom ash.

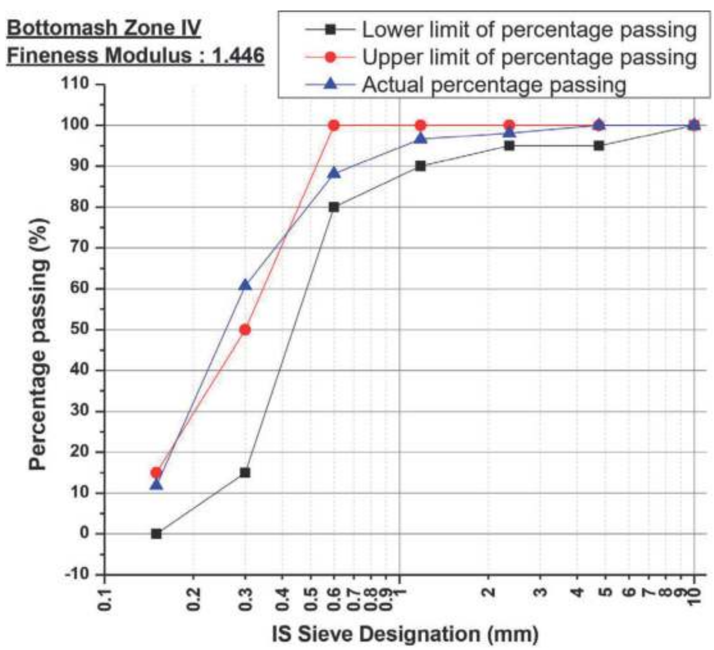

Figure 5.
Grading curve of bottom ash as per IS 383 by sieve analysis [29].

protocol. This setup was constructed using high insulating material, extruded polystyrene, whose thermal conductivity is 0.027 W/m K. This setup is capable to measure the U-value of any material whose thermal conductance is in the range of 0.1 W/m^2 K to 15 W/m^2 K. The testing of U-value of 125 mm thick burnt clay brick wall was done in both the cold side open and closed condition (**Figure 7**).

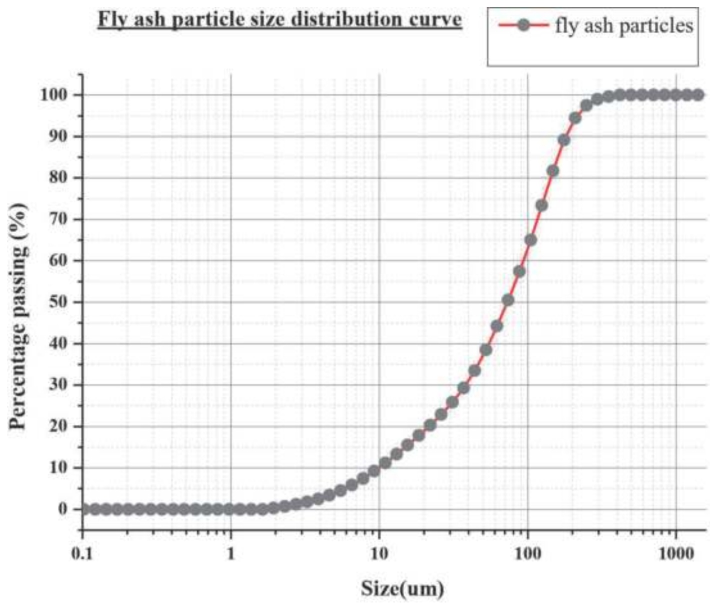

Figure 6.
Particle size distribution for fly ash, used in the experiment.

Mix identity	Cement	Sand	Flyash	Bottomash	Stone Aggregate	Water-cement ratio
CC	1	1.60	—	—	2.40	0.50
BC-1	1	1.44	—	0.16	2.40	0.50
BC-2	1	1.28	—	0.32	2.40	0.50
BC-3	1	1.12	—	0.48	2.40	0.50
BC-4	1	0.96	—	0.64	2.40	0.50
BC-5	1	0.80	—	0.80	2.40	0.50
BC-6	1	0.64	—	0.96	2.40	0.50
BC-7	1	0.48	—	1.12	2.40	0.50
BC-8	1	0.32	—	1.28	2.40	0.50
BC-9	1	0.16	—	1.44	2.40	0.50
BC-10	1	0.00	—	1.60	2.40	0.50
FC-1	1	1.44	0.16	—	2.40	0.50
FC-2	1	1.28	0.32	—	2.40	0.50
FC-3	1	1.12	0.48	—	2.40	0.50
FC-4	1	0.96	0.64	—	2.40	0.50
FC-5	1	0.80	0.80	—	2.40	0.50
FC-6	1	0.64	0.96	—	2.40	0.50
FC-7	1	0.48	1.12	—	2.40	0.50
FC-8	1	0.32	1.28	—	2.40	0.50
FC-9	1	0.16	1.44	—	2.40	0.50
FC-10	1	0.00	1.60	—	2.40	0.50

Table 2.
Design mix concrete of M-25 grade with fly ash/bottom ash substitution separately.

Sample identity	Cement	Lime dust	Fly ash	Bottom ash	Stone aggregate	Water-cement ratio
42(75:25)	1.00	0.40	—	1.20	2.40	0.50
41(67:33)	1.00	0.53	—	1.07	2.40	0.50
40(50:50)	1.00	0.80	—	0.80	2.40	0.50
39(75:25)	1.00	0.40	1.20	—	2.40	0.50
38(67:33)	1.00	0.53	1.07	—	2.40	0.50
37(50:50)	1.00	0.80	0.80	—	2.40	0.50

Table 3.
Design mix concrete of M-25 grade lime dust and fly ash/bottom ash (no sand).

Mortar mix identity	Mortar mix (MM3 grade)	Cement wt. ratio	Sand wt. ratio	Flyash wt. ratio	Bottomash wt. ratio
Control	1 cement:6 and	1.00	6.00	—	—
A-1	1 cement:(5.4 sand + 0.6 flyash)	1.00	5.40	0.60	—
A-2	1 cement:(4.8 sand + 1.2 flyash)	1.00	4.80	1.20	—
A-3	1 cement:(4.2 sand + 1.8 flyash)	1.00	4.20	1.80	—
A-4	1 cement:(3.6 sand + 2.4 flyash)	1.00	3.60	2.40	—
A-5	1 cement:(3.0 sand + 3.0 flyash)	1.00	3.00	3.00	—
A-6	1 cement:(2.4 sand + 3.6 flyash)	1.00	2.40	3.60	—
A-7	1 cement:(1.8 sand + 4.2 flyash)	1.00	1.80	4.20	—
A-8	1 cement:(1.2 sand + 4.8 flyash)	1.00	1.20	4.80	—
A-9	1 cement:(0.6 sand + 5.4 flyash)	1.00	0.60	5.40	—
A-10	1 cement:6 flyash	1.00	0.00	6.00	—
B-1	1 cement:(5.4 sand + 0.6 bottomash)	1.00	5.40	—	0.60
B-2	1 cement:(4.8 sand + 1.2 bottomash)	1.00	4.80	—	1.20
B-3	1 cement:(4.2 sand + 1.8 bottomash)	1.00	4.20	—	1.80
B-4	1 cement:(3.6 sand + 2.4 bottomash)	1.00	3.60	—	2.40
B-5	1 cement:(3.0 sand + 3.0 bottomash)	1.00	3.00	—	3.00

Mortar mix identity	Mortar mix (MM3 grade)	Cement wt. ratio	Sand wt. ratio	Flyash wt. ratio	Bottomash wt. ratio
B-6	1 cement:(2.4 sand + 3.6 bottomash)	1.00	2.40	—	3.60
B-7	1 cement:(1.8 sand + 4.2 bottomash)	1.00	1.80	—	4.20
B-8	1 cement:(1.2 sand + 4.8 bottomash)	1.00	1.20	—	4.80
B-9	1 cement:(0.6 sand + 5.4 bottom ash)	1.00	0.60	—	5.40
B-10	1 cement:6 bottomash	1.00	0.00	—	6.00

Table 4.
Masonry mortar mix of MM 3 grade with fly ash/bottom ash substitution separately.

Mortar mix identityy	Mortar Mix (MM3 grade)	Cement	Sand	Fly ash	Bottom ash	Lime dust	Marble dust
1	1 cement:6 sand	1.00	6.00	—	—	—	—
2	1 cement:6 (3.0 limedust+3.0 flyash)	1.00	—	3.00	—	3.00	—
3	1 cement:6 (3.0 marbledust + 3.0 flyash)	1.00	—	3.00	—	—	3.00
4	1 cement:6 flyash	1.00	—	6.00	—	—	—
5	1 cement:6 (3.0 limedust + 3.0 bottomash)	1.00	—	—	3.00	3.00	—
6	1 cement:6 (3.0 marbledust + 3.0 bottomash)	1.00	—	—	3.00	—	3.00
7	1 cement:6 bottomash)	1.00	—	—	6.00	—	—

Table 5.
Masonry mortar mix of MM 3 grade with fly ash/bottom ash and lime dust/marble dust.

Two wooden frames having dimension 500 × 500 were built in order to construct and hold the brick wall samples within those. This was done mainly in order to make it a modular system which could be portable enough so that after experimentation further developments of the samples like plastering, coloring etc. are feasible. Clay bricks, Portland Pozzolana Cement (PPC), sand, fly ash, lime dust and water were the raw materials used for the construction of the brick walls. Dimension of standard Indian burnt clay bricks are 230 × 115 × 75. Two sets of brick walls were developed for the experimentation purpose, one with conventional plaster grade MM5 with cement-sand ratio 1:4, another one with same grade of mortar and plaster but with 50% Lime dust and 50% fly ash in place of 100% sand. Dimensions of the both brick walls were 480 × 480 × 115 and 480 × 480 × 115 with 12 mm plaster on either side.

Figure 7.
Guarded hot box test setup with data logging and wall panel under preparation.

4. Experimental results

4.1 Compressive strength and thermal conductivity test results

As described in previous chapter, i.e. Chapter 3, all the design and nominal mix samples in respect of Concrete of various grades starting from M-15 to M-25 were put to test to determine various physical and thermal parameters. Similarly, Mortar mix samples of various proportions with respect to two most used grades MM3 and MM5 were put to tests. The tests performed on those samples were of destructive and non-destructive in nature. The tests are essential for durability and application worthiness of such concrete and mortar mixes (**Figures 8–15**).

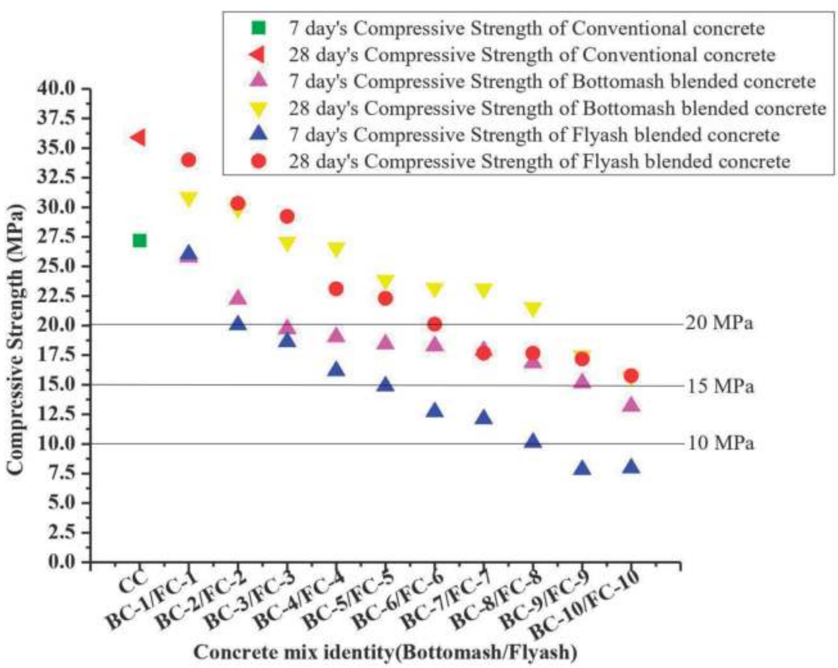

Figure 8.
*Compressive strength of concrete mix (refer **Table 2** for mix proportion).*

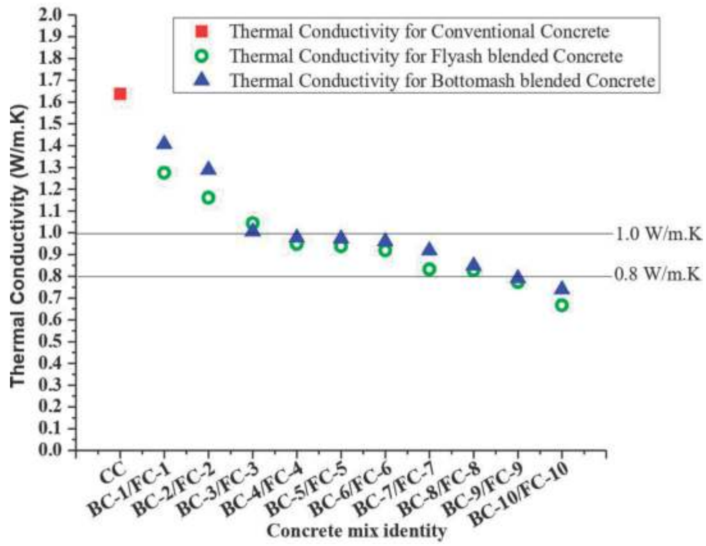

Figure 9.
Thermal conductivity test results of concrete mix (refer ***Table 2*** *for mix proportion).*

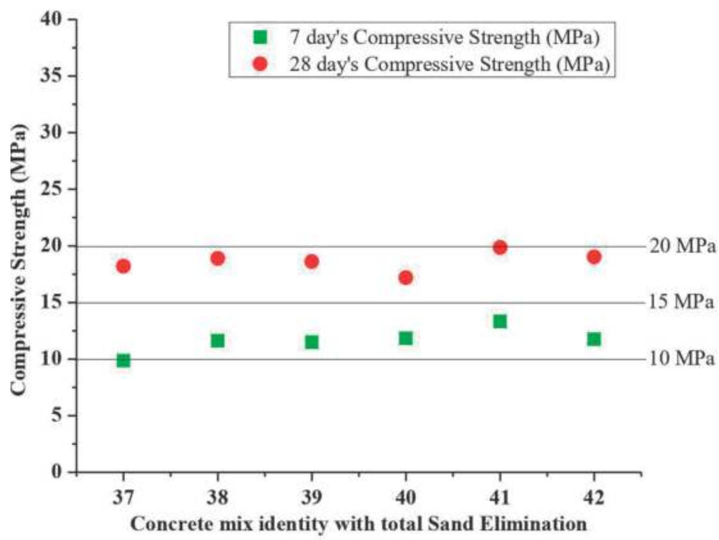

Figure 10.
Compressive strength test of concrete mix (refer ***Table 3*** *for mix proportion).*

It may be seen from the above plotted results, bottomash blended concrete offers M-25 grade strength up to 40% replacement and M-20 grade strength up to 80% replacement of sand. Fly ash blended concrete gives marginally lower results.

It may be seen from the above plotted thermal conductivity test results, both fly ash and bottom ash blended concrete offer reduced thermal conductivity than conventional concrete mix.

From the above plotted result, it may be observed that flyash-lime dust (38) and bottomash-limedust (41) blended mix in the ratio of 67:33 offer M-20 grade strength and same combination with 75:25 ratio offer close to M-20 grade strength.

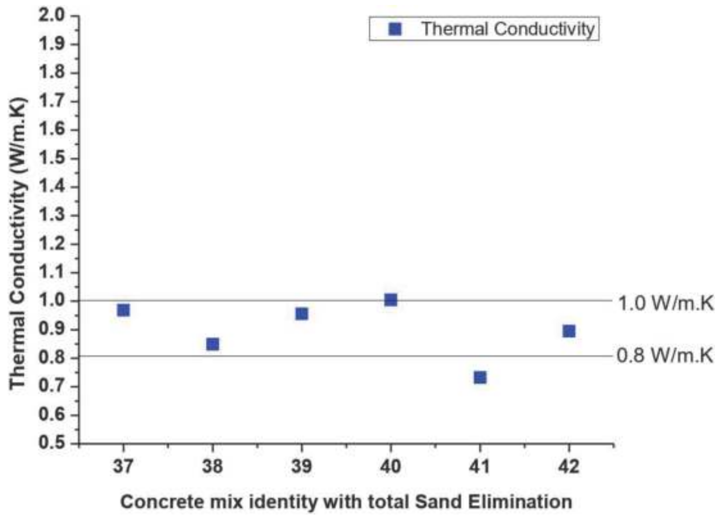

Figure 11.
*Thermal conductivity test of concrete mix (refer **Table 3** for mix proportion).*

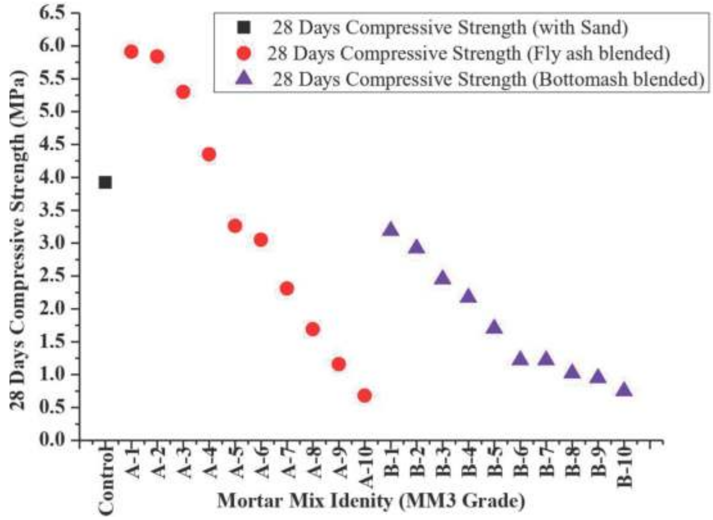

Figure 12.
*Compressive strength test of mortar mix (MM3) (refer **Table 4** for mix proportion).*

Mixes 38 (flyash:limedust::67:33) and 41 (bottomash:limedust::67:33) offer lower thermal conductivity value.

From the above plotted result, it may be observed that up to 60% replacement of sand by flyash, strength remains within MM-3 grade required criteria.

Reduction in thermal conductivity value follows same trend by fly ash and bottom ash blended mortar mixes respectively.

Flyash-limedust (2) and bottomash-limedust combination offer MM-3 grade strength compatibility.

Considerable reduction in thermal conductivity values observed in both flyash (2, 3, 4) and bottomash (5, 6, 7) blended mixes with respect to the conventional mix (1).

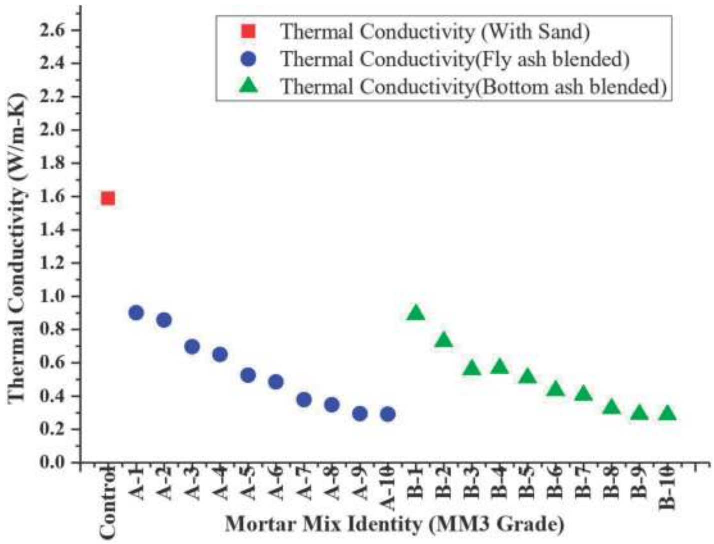

Figure 13.
Thermal conductivity test results of mortar mix (refer ***Table 4*** *for mix proportion).*

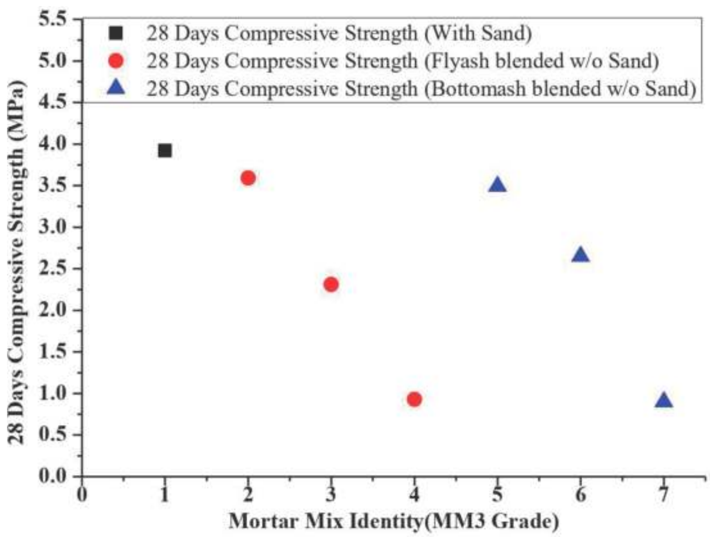

Figure 14.
Compressive strength test values of MM3 grade mortar (total replacement of sand by flyash, lime dust, marble dust, bottomash) (refer ***Table 5****).*

4.2 Test result for overall heat transfer co-efficient (U-value)

The hot side temperature of 40°C, and cold side temperature of 25°C were maintained for 3 consecutive days. Both the brick wall panels with conventional mortar and plaster combination and fly ash-lime dust combination were tested under identical test parameters. In steady state condition, average standard deviation in brick surface temperature of both days of testing was 0.056°C on both the hot and cold side. The experimentally obtained U-values for both the cases and final difference thereof is shown in **Table 6**.

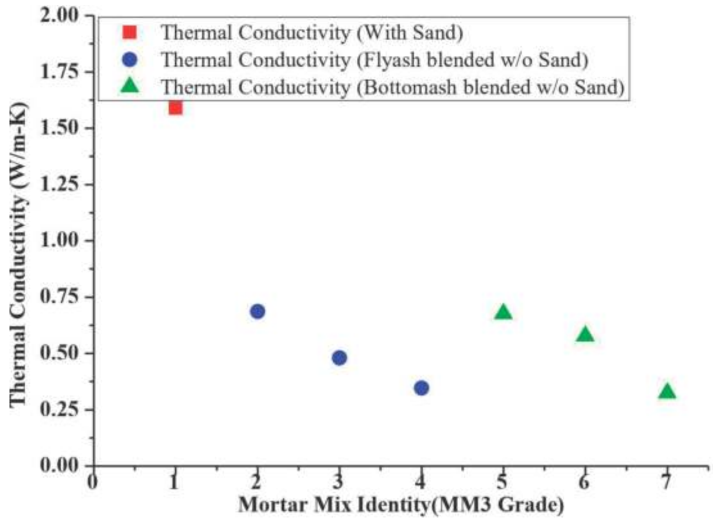

Figure 15.
*Thermal conductivity test results of mortar mix (refer **Table** 5).*

Wall sample with cement-flyash-lime mortar mix		Wall sample with cement-sand mortar mix	
Days	**U-value (W/m^2 K)**	**Days**	**U-value (W/m^2 K)**
Day 1	3.051	Day 4	3.655
Day 2	2.954	Day 5	3.534
Day 3	3.050	Day 6	3.536
Average of 3 days	3.018	Average of 3 days	3.575
Difference in U-value (%)		15.58	

Table 6.
Final result of wall panel U-value.

5. Economical and environmental benefits

A square shaped room of size 10 m^2 plan area and four wall size each of 10 m^2 is considered for such energy and economic analysis at Kolkata, India location.

5.1 Assumptions

i. The outside average temperature in a month is considered as 30°C, and inside conditioned temperature as 25°C during entire duration of activity of 8 h in a day.

ii. Active days in a month is considered as 26 days.

iii. Average electricity tariff considered as Rs.8/- per unit of electricity consumed.

Room (m^2)	Walls (m^2)	Diff. in temp (°C)	U-value for roof assembly (W/ m^2 K)	U-value for wall assembly (W/ m^2 K)	Active hours in a month (h)	Total energy flow thro' roof (kWh)	Total energy flow thro' walls (kWh)	Gross energy (kWh)	Savings per month (Rs.)	CO_2 saved per month (kg)
10	40	5	3.3371	3.5750	208	34.71	148.72	183.43		
10	40	5	2.6187	3.0180	208	27.23	125.55	152.78	245.20	25.13

Table 7.
Economic and environmental analysis.

iv. RCC (of M-20 grade blended concrete) roof slab thickness considered as 125 mm, overlaid by 50 mm thick PCC (of M-15 grade blended concrete), and topping by 25 mm thick PCC (M-15 grade blended concrete without sand).

v. Masonry wall thickness 125 mm, made of burnt clay brick and mortar (of MM-3 grade), plastered both sides with 12 mm thick plaster of same grade.

vi. CO_2 emission due to energy generation from thermal power plant is considered as 0.82 kg per kWh

6. Conclusions

From the study pertaining to this work, the following can be concluded:

1. Fly ash and Bottom ash, the 100% utilization of which is still not possible, might follow a positive note. Building industry could be immensely benefitted by such usage from the perspectives of 3Es, Economy, Environment and Energy. The benefit for the case example under Section 5 is shown in **Table 7.**

2. Other than electrical energy saving due to the inherent insulating nature, coal ash is available free of cost from all thermal power plants and even transportation cost up to 100 km radius is reimbursed in India by the Plant authorities. The mechanical dredging required to extract sand from river bed is totally avoided in such substitution.

3. Since the rate of formation outpace rate of extraction due to infrastructure developmental need, sand is being depleted rapidly worldwide. Rampant sand mining from river bed is causing serious environmental imbalances like lowering of water table in the adjacent agricultural field, river bank erosion, disturbing effect on aquatic life etc. At the same time, continuous accumulation of coal combustion residues since ages, pose serious health threats in the adjoining areas of ash dykes. These two issues could be compensated by the proposed substitution.

4. The research work did not involve any energy consuming machinery or technique and no synthetic additive was used.

5. Energy saving out of such substitution is one of the major finding, which would contribute to abatement of rising CO_2 emission. Substitution in masonry mortar

could lower U-value by 15.58% (**Table 7**), which is translated into reduction in considerable electrical energy requirement to maintain comfort condition in buildings.

6. Such substitution of coal ash in concrete and mortar mixes in building construction could also contribute significantly in the concept of Near Zero Energy Building by restricting its specific energy demand up to certain extent. It could also provide impetus to Green and Affordable Housing program.

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Conflict of interest

The author declare that there remains no scope for conflict of interest.

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