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Preservation of Sand and Building Energy Conservation

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Abstract

Due to developmental need of humankind, growing trend of energy generation and consumption results more and more Green House Gas emissions, which contribute significantly to the phenomena of Climate Change and Global Warming. The issue is further compounded by huge ash generation from thermal power plants. Judicious utilization of such waste in a greener way is another challenge. It is estimated that by 2030, 40.8% of Indian population shall be living under Urban environment, and huge no. of dwelling units would be required. Sand, being one of the conventional constituent of Concrete, and also the non-renewable soft mineral, is being mined mindlessly across the Globe. The energy consumed by building sector is around 40% of global energy use. HVAC load is the major contributor in overall energy profile in buildings situated under Hot & Humid climatic zones in tropical countries. Solar heat gain is resulted through building envelope, and the conventional concrete and plastered masonry surfaces contribute significantly to the same. An experimental work has been carried out to produce sustainable energy efficient concrete with Portland Pozzolana Cement, Sand, Coal Ash from Thermal Power Plant, Stone aggregate and water. Test samples are prepared with reducing quantities of Sand and increasing quantities of Coal Ash for a Design Mix Concrete. While characteristic strength of concrete could be achieved with replacement of Sand by Coal Ash, thermal conductivity value of concrete is reduced, while compared with normal concrete of same Mix.

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Keywords: Sand, Energy; Fly ash; Bottom Ash; Thermal conductivity

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1. Introduction

1.1 Climate change and effect of thermal energy generation

Human activities are influencing the climate and the trend in recent anthropogenic emissions of greenhouse gases is found to be the highest. Fossil fuel combustion and industrial processes together attributed around 78% of total Green House Gas (GHG) emission's increase during the period from 1970 to 2010. Considering the global scenario, population increase and economic growth are the two key contributors in CO2 emission from fossil fuel combustion. [1] Coal based thermal power plants contribute around 65% of the total electricity generation in India, and the ash content in the coal used in Indian thermal power plants vary between 25-45% [2]. Considering various sectors (Transport, Industry, Cooking, Building, Telecom, Pumps and Tractors) from electricity demand point of view in India, Building Sector demand is projected to touch 2287 TWh in 2047 from a figure of 238 TWh in 2012 (around 49% of total electricity demand shall arise from Building sector alone). The projected total installed capacity of Coal based power stations shall stand at 333 GW, which will generate around 1963 TWh of electricity in 2047 [3].

1.2 Coal ash generation and its impact

In India, 130 Coal based power plants are producing around 165 M.T. of ash per year [4]. The pulverized coal when burnt, produces ash in the category of flay ash 80% and bottom ash (coarser variety) 20% [5]. The effective disposal of fly ash is a critical proposition. Fly ash is being used widely as constituent of Portland Pozzolana Cement, as Building Blocks / Bricks, Landfill and Embankment constructions, and to some limited extent for agriculture purpose. Disposal of ash in slurry state in low lying areas/dumping yards cause leaching and serious ground water pollution in adjoining areas. It also creates a state of suspended respiratory particulate matter under dry state in the air, which is extremely hazardous for human health.

1.3 Sand, a major constituent of concrete and masonry in construction industry

With the above projection in Building Sector, huge quantities of concrete would be required, and as a natural consequence, sand, one of the key ingredient would also be required in justified proportions. With the mindless sand mining from the river bed, ecological balances are disturbed in the form of depletion in ground water table, lesser availability of water for agricultural, industrial and drinking purposes, destruction of agricultural land, damage to roads and bridges etc.[6].

1.4 Other works and Energy conservation

P. Aggarwal et al. [7] had investigated about the effect of bottom ash in concrete, as partial replacement of fine aggregate component. Dan Ravina et al. [8] had studied the role of Class F fly ash in properties of concrete as partial replacement of fine sand. Kadam et al. [9] had made an experimental study to see the effects of coal bottom ash as fine aggregates in place of sand in varying proportions in concrete and various physical parameters viz. Compressive strength, tensile strength, flexural strength, modulus of elasticity, density, water permeability etc. were noted. Fine aggregate replacement by low Calcium ash in plain concrete, and the resultant effect on mechanical properties of concrete was studied by Siddique et al.[10] Deo et al. [11] had undertaken long term comparative study on concrete mix design procedure for fine aggregate replacement by fly ash with the help of Minimum Voids Method and Maximum Density Method. Rajamane et al. [12] had evolved formulation with respect to prediction of compressive strength of concrete when sand is replaced by fly ash. Demirboga et al. [13] had noted the influential effect of mineral admixtures on thermal conductivity and compressive strength of mortar. To address the issues listed at 1.1-1.3, reduction in sand content and replacing the same by coal bottom ash can be proved beneficial from energy conservation point of view.

2. Experimental Study

2.1 Considerations

In the present research work, a comparison has been made with normal concrete and sand replaced by coal bottom ash concrete from strength point of view and heat conductivity point of views respectively. In the experimental study, the mix has been designed as per IS Code, and the proportions of various ingredients have been arrived at accordingly.

A cement concrete design mix of arrived proportion was considered. Bottom ash concretes with bottom ash as sand replacement with varying proportions were undertaken. Samples were prepared for each proportion and were tested to find out the compressive strength at 7 Days, 28 Days and conductivity values respectively. Change in conductivity value with changed proportion of bottom ash as sand replacement were noted.

2.2 Materials for experiment

Cement used was Portland Pozzolana Cement (PPC) from commercially available brand, complying with IS 1489 (Part.1) : 1991 [14], Fly ash (FA) / Bottom ash (BA) conforming IS 3812 (Part 1) : 2003 [15], Sand, and10 mm down aggregate conforming to IS 383 : 1970 (Reaffirmed 2002) [16] and potable water were used for this work.

Table 1 Chemical composition of PPC, FA & BA

Chemical constituent	Portland Pozzolana Cement	Fly ash	Bottom ash
SiO_2	32.38	54.07	60.71
Al_2O_3	10.21	26.73	25.86
Fe_2O_3	3.97	6.87	6.81
CaO	41.67	0.97	0.89
MgO	1.49	0.7	0.63
Na_2O	0.32	0.39	0.38
K_2O	1.25	1.86	1.28
TiO_2	0.71	2.56	1.97
SO_3	3.73	0.71	0.15
LOI	3.21	3.74	0.92
Free Moisture	0.96	0.28	0.14

Table 2 Sp. Gravity values of PPC, FA, BA, Sand and Coarse aggregate

Description	Portland Pozzolana Cement	Fly ash	Bottom ash	Sand	Coarse aggregate
Sp. Gravity	3.15	2.43	2.46	2.65	2.70

Specific gravity test was performed following IS 1122-1974 (Reaffirmed 2003) [17]

2.3 Mix Calculations done as per IS 10262 : 2009[18], the steps are described broadly, as below -

Target strength for Mix: $f'_{ck} = f_{ck} + 1.65s$ (1)

where, f'_{ck}= target average compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days, ands = standard deviation.

Selection of Water-Cement Ratio – From Table 5 of IS 456: 2000 [19],

Selection of Water & Cement content –

From Table-2 of IS 10262, Maximum Water content for 10 mm aggregate is taken and Cement content is calculated accordingly.

Selection of Sand content – Corresponding to W/C& Workability (Applicable for Concrete grade up to M 35) ,according to IS 10262.

Adjustment of values in Sand content & Water content , as applicable –

Entrapped Air content is considered as per IS 10262 .

Determination of Coarse & Fine aggregate content was possible by solving Equations 2 and 3 below–

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p} * \frac{f_a}{S_{fa}}\right] * \frac{1}{1000} \quad (2)$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p} * \frac{C_a}{S_{ca}}\right] * \frac{1}{1000} \quad (3)$$

where, V = absolute volume of fresh concrete = gross volume (1 m^3) minus the volume of entrapped air,

S_c= specific gravity of Cement,

W = mass of water (kg) per m^3 of Concrete,

C = mass of Cement (kg) per m^3 of Concrete,

p = ratio of fine aggregate to total aggregate by absolute volume,

f_a , C_a = total masses of fine aggregate and coarse aggregate (kg) per m^3 of Concrete respectively,

S_{fa} , S_{ca} = specific gravities of saturated surface dry fine aggregate and coarse aggregate respectively.

Solving Equations (2) and (3), the Mix proportion becomes -

$$C : f_a : C_{sa} :: 1 : 1.5 : 2.5$$

By repeating the above steps, but without adjustment in Sand or Water Content, the Mix proportion worked out

$$C : f_a : C_{sa} :: 1 : 1.6 : 2.4$$

2.4 Preparation of Samples and Testing

Concrete samples with above proportion was prepared as Controlled one, and thereafter reducing the Sand content by 10% in each successive mix, and replacing the same by bottom ash of equal weight . Conductivity value (k) was measured for samples of above Mix by Hot Disk [20], based on Transient Plane Source Technique.

Two inches Concrete cubes were prepared for determination of compressive strength at 7 days and at 28 days respectively as per IS 516 – 1959 (Reaffirmed 2004) [21]. The Compressive strength of concrete cube samples were tested under compression loading in Universal Testing Machine.

Samples of size 50 mm by 50 mm and thickness 25 mm / 12 mm were used to determine thermal conductivity value by Transient Plane Source (TPS) method. This is one of the most precise and less time consuming techniques for studying thermal transport properties. The method uses transiently heated plane sensor, which consists of an electrically conducting pattern in double spiral shape, etched out of a thin Nickel foil. The spiral remains in between two thin layers of insulating material - Kapton, Mica etc. The Hot Disk sensor is fitted between two identical sized samples, each one with a plane surface, touching the sensor. Electric current of pre-determined value is passed to increase the temperature of the sensor, and simultaneously recording the resistance increase as a function of time.

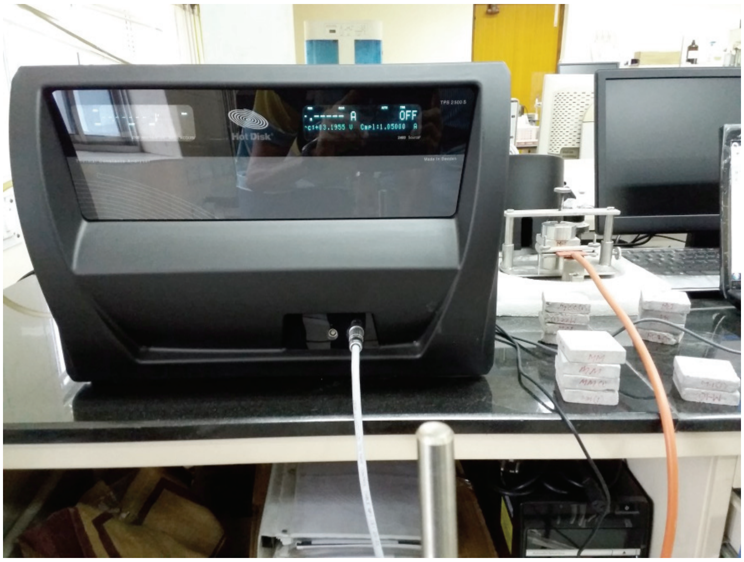

Fig.1 Thermal Conductivity Test Set up

Table 3 Details of Concrete Mixes

Sl.	Identification of Mix	Remarks
1.	CC	Controlled Concrete with Cement, Sand, Aggregate and Water for Mix 1:1.6:2.4.
2.	D-1	Having 10% of Sand quantity replacement by Ash, for same Mix.
3.	D-2	Having 20% of Sand quantity replacement by Ash, for same Mix
4.	D-3	Having 30% of Sand quantity replacement by Ash, for same Mix
5.	D-4	Having 40% of Sand quantity replacement by Ash, for same Mix
6.	D-5	Having 50% of Sand quantity replacement by Ash, for same Mix
7.	D-6	Having 60% of Sand quantity replacement by Ash, for same Mix
8.	D-7	Having 70% of Sand quantity replacement by Ash, for same Mix
9.	D-8	Having 80% of Sand quantity replacement by Ash, for same Mix
10.	D-9	Having 90% of Sand quantity replacement by Ash, for same Mix
11.	D-10	Having 100% of Sand quantity replacement by Ash, for same Mix

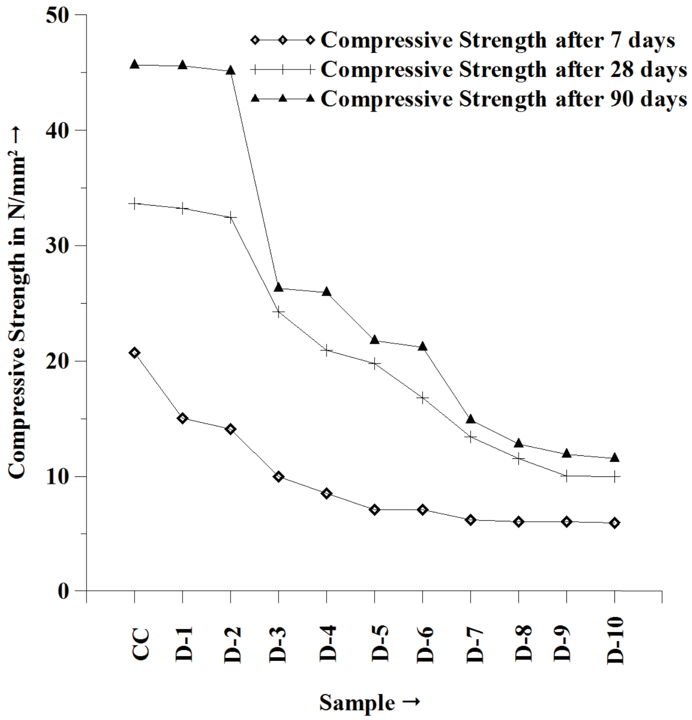

Fig.2 Graphical presentation about variations in Compressive Strength of different Concrete Mixes.

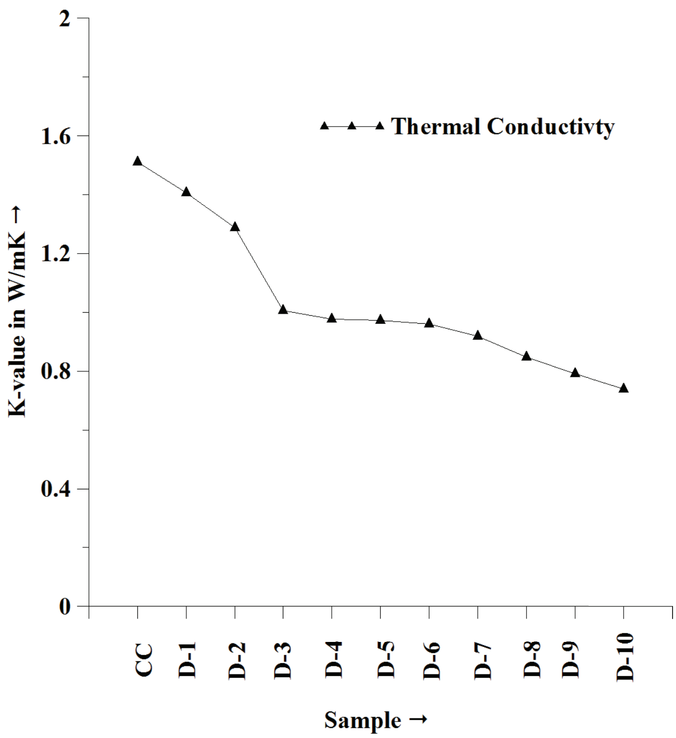

Fig.3 Graphical presentation about variations in Thermal Conductivity (k) values of different Concrete Mixes.

Similarly Cement- Sand and Cement – Fly ash / Cement – Fly ash – Lime Mortar Mix proportions were also studied, and "k" value reduction results were obtained.

Table 4 Details of Mortar Mixes

Sl.	Identification of Mix	Remarks
1.	A1	Cement : Sand is 1:6, Grade MM3
2.	A2	Cement : Sand is 1:4, Grade MM5
3.	A3	Cement : Fly ash is 1:6.
4.	A4	Cement : Fly ash is 1:4.
5.	A5	Cement : Fly ash : Lime = 1:3:3
6.	A6	Cement : Fly ash : Lime = 1:2:2

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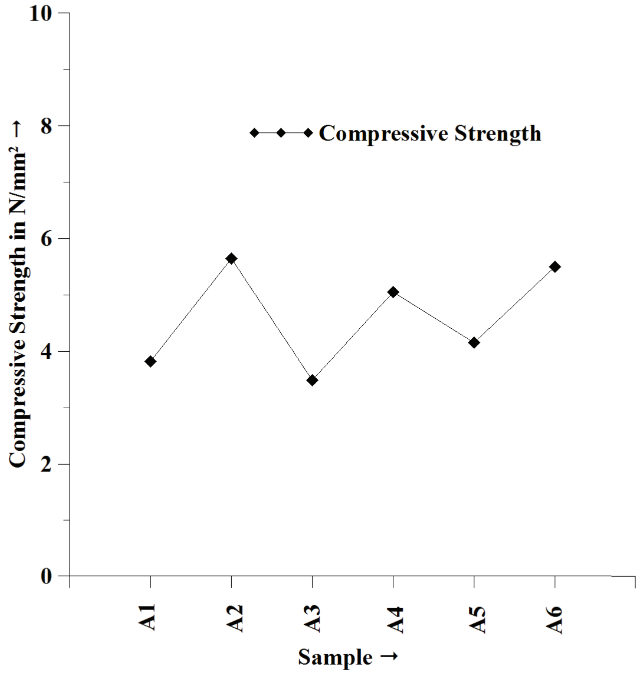

Fig.4 Graphical presentation about variations in Compressive Strength of different Mortar Mixes

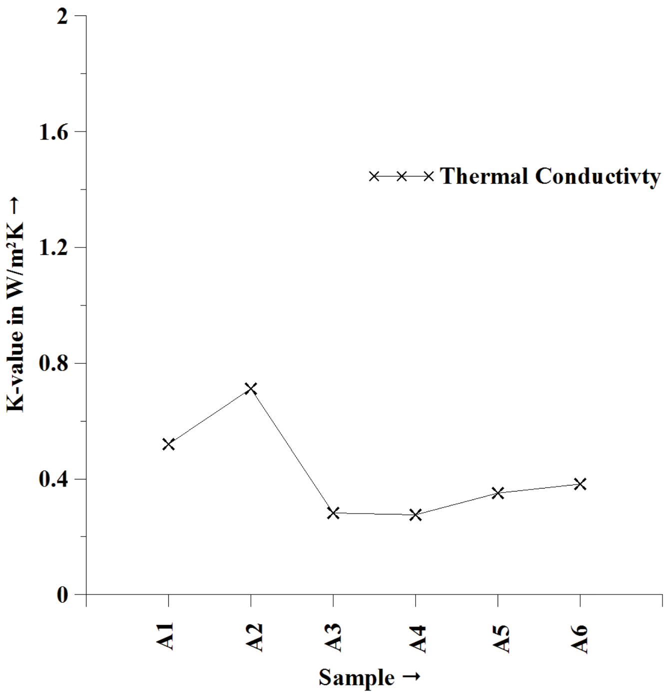

Fig.5 Graphical presentation about variations in Thermal Conductivity (k) values of different Mortar Mixes.

3. Results and discussions

From the graph in Fig.2, it may be observed that from compressive strength point of view, samples marked CC to D 3, have attained more than M-25 strength at 28 days curing condition and D 4 sample has attained M 20 strength at 28 days curing conditions respectively. D 5 and D 6 samples have attained more than M 15 strength at 28 days curing condition and M 20 strength at 90 days curing conditions respectively. D 7 to D 10 samples have attained more than M 10 strength at 28 days curing condition and M 12 strength at 90 days curing conditions respectively.

From the graph in Fig.3, it may be observed that, for 40% replacement case (D 4) , thermal conductivity value has been reduced by around 35%, for 60% replacement case (D 6), thermal conductivity value has been reduced by 36.5% , and for 100% replacement case (D 10), thermal conductivity value has further been reduced by around 51%. All are compared with the base case sample (CC).

Similarly, from the graph in Fig.4, it is observed that samples marked A 3 and A 4, both attained compressive strength values at 28 days curing conditions around M 3 and M 5 respectively, which conforms to IS 2250 :1981 (Reaffirmed 2000) [22]. For mixes with marking A 5 and A 6, the compressive strength values at 28 days curing conditions are around M 4 and M 5.5 respectively. Compressive strengths for samples marked A 1 and A 2 for 28 days curing conditions are also shown.

From the graph in Fig.5, it is observed that for cement- sand mortar with 1:6 proportion (A 1) is compared with cement - fly ash with same proportion (Sample mark A 3), and found the same with 46% lesser conductivity than the base case sample (A 1). Cement - sand mortar with 1:4 composition (Sample mark A 2) is compared with cement - fly ash identical composition (Sample mark A 4). It is observed that the thermal conductivity value is reduced by 61% than the base case sample (A 2).

4. Energy impact out of this finding

Considering a room size of 3m by 4m in plan dimension, and outside room temperature as 40^0 C (exposed to direct Solar radiation) and inside electro-mechanically controlled temperature as 25^0 C, and thermal conductivity of screed concrete layer of 25 mm in the base case scenario (Cement : Sand : Stone aggregate :: 1:1.6:2.4) for sample

CC and for Ash concrete sample D 6, the conductive heat gain through the exposed roof are worked out as 10879 Watts and 6913 Watts respectively. For an 8 hour use room under controlled temperature condition and considering 26 working days in a month, the difference in energy quantity is worked out as 825 kWh. The corresponding monthly saving in monetary term is Rs.6930.00 (@ Rs.8.40/- per kWh) , and CO_2 emission avoided shall be in the tune of 660 kg monthly at the user end.

5. Conclusion

From the above experimental data, it may be concluded that by replacing sand with Coal ash, natural soft mineral can be preserved, and the water table balance can be ensured. Further, Energy Conservation in Building industry is possible up to a considerable extent, by reducing Solar heat ingress through Building envelope, and resultant reduction in mechanical cooling load.

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