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INFLUENCE OF HIGH TEMPERATURE ON COMPRESSIVE STRENGTH OF COAL BOTTOM ASH CONCRETE

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Abstract: It is very important to observe the thermal stability of concrete when exposure to higher temperatures. So, this study aims to find the effect of elevated temperature on the residual compressive strength of concrete containing Coal Bottom Ash (CBA). Five concrete mixtures were prepared at different replacement levels of CBA (0%, 10%, 20%, 30%, and 40%) with fine aggregates and subjected to different temperature levels. Sixty cubes were casted (with three cubes for each testing condition) and cured for 28 days. Then after, they were heated to 150^{0}C, 300^{0}C and 600^{0}C for two and half hour duration in the muffle furnace. The significant strength loss was observed for all type of concrete after exposure to 150^{0}C. There was more critical strength loss for reference as well as CBA concrete, when heated in range of 300-600^{0}C. Based on the test results, it can be concluded that the replacement of fine aggregates with CBA cannot change the strength properties of concrete during heating.
Keywords: Coal Bottom Ash, Compressive Strength, Concrete, Elevated Temperature, Workability.

INTRODUCTION

Concrete is most widely used building material in civil engineering due to its durability. It is a manmade composite, consisting of a mixture of cement, aggregates, water and admixture. Due to development in infrastructure all around the world, utilization of concrete is increasing at a higher rate. Natural aggregates such as gravel or crushed rock and sand are the major constituent of the concrete. Few decades ago, these aggregates have been easily available at economic prices. But, the negative impact of increasing demand for concrete is leading to extensive extraction of aggregates from natural resources. This excessive extraction results into environmental degradation, ecological imbalance and create a question about the preservation of natural resources of aggregates. So, it has challenge to every engineer and researcher to develop new materials which can replace the aggregates, and mitigate the problems, related to preservation of natural resources of aggregates. Apart from it, the amount and type of industrial waste have increased due to normal growth in

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population. Many of industrial waste such as Coal bottom ash, Blast furnace slag, Copper slag etc. cause a waste disposal crisis, thereby leading to the environmental problems. However, this environmental problem can be reduced by making more appropriate use of the industrial waste. The use of industrial waste in concrete is a suitable path towards effective disposal of waste as well as preservation of natural resources of aggregates. Several researchers have investigated the optimum use of CBA as fine aggregates in concrete and its effects on the different mechanical and durability properties. The properties of CBA are much similar to fine aggregates. Therefore it could be regarded as the substitute of the fine aggregates in concrete construction. The use of this ash in concrete provides potential environmental as well as economic benefits for concrete industries and particularly in thermal power plant where a considerable amount of CBA is produced.

CBA is the waste product of coal fired power plant. It is a non combustible material produced after burning of coal in furnace of coal fired thermal power plants. After burning of coal, the clinkers build up and fall to the bottom hopper of the boiler. Thereafter, clinkers are cooled in the water sump before grinding. In India, over 70% of electricity is generated by combustion of fossil fuels, out of which nearly 61% is produced by coal fired plants (Aggarwal *et al* 2007). The coal fired thermal power plants burn about 407 million tons of coal for generation of power and produce about 131 million tons of coal ash annually (Singh and Siddique 2014). The resulting ash has to be disposed off either dry or wet to an open area near the plant or mixing it with water and pumping into water bodies. This causes pollution. To mitigate this type of problem, it is necessary to utilization of coal bottom ash. The CBA is composed of mainly silica, alumina and iron with small amount of calcium, magnesium sulfate etc. (Singh and Siddique 2014). It is also observed that the coal bottom ash is well graded and majority of its grain sizes lies between 4.75 mm to 0.6 mm. This grain size of CBA is within the limit given by IS: 383-1970 (Kadam and Patil 2013). These properties of coal bottom ash make it attractive to be used as fine aggregates in production of concrete.

Sometimes concrete structures are exposed to fire. Fire decreases the durability and strength of such concrete structures. Meanwhile, the resistance capacity of ordinary concrete against fire alone is very complicated because concrete is a composite material with components having different thermal properties. Fire resistance of concrete depends upon many factors like the size and shape of structures, type of admixtures, cement and aggregates used. Aggregates have very high resistance against the fire but cooling of the heated aggregates may results to formation of internal pressure. This internal pressure may cause of changes the volume of aggregates. Hydrated Portland cement contains a significant amount of free calcium hydroxide and will decompose into calcium oxide due to loss of water at 400–450^{0}C (Metin Husem 2005). This calcium oxide changes into calcium hydroxide again, when kept under moist environment. These chemicals changes are responsible for contraction of cement paste. Some of the deformation of concrete is due to this contraction. Due to such changes in volume of aggregates and cement paste, the concrete may spall. In fact, normal concrete can be with stand up to about 100–120^{0}C without any significant loss in compressive strength. It is feared therefore that addition of CBA into concrete might changes the properties of concrete at higher temperature.

Several researchers have investigated the strength, workability and durability characteristics of concrete using CBA (as partial replacement of fine aggregates). The information available on the performance with regard to properties of concrete using CBA, at elevated temperature is limited. The prime objective of this research is to examine the loss in compressive strength of CBA concrete in response to elevated temperatures.

MATERIALS USED

Cement

In present investigation Ordinary Portland Cement (OPC) of 43 grades conformed to IS: 12269:1987 was used. The physical properties of the cement obtained on conducting some appropriate tests. Cement was carefully stored to protect from moisture.

Fine aggregates

Natural sand was used as fine aggregates, collected from Chakki River (Pathankot). The physical properties of fine aggregate are used in this study, conformed to IS: 383-1970. Specific gravity of fine aggregates was determined as 2.71 and conformed to grading zone II. It was brown in color with coarser shape of particles.

Coarse aggregates

Crushed gravel used in present study was collected from Pathankot quarry. It was a mixture of two stone sizes of 10 mm and 20 mm, with equal proportions. These were washed to remove dirt, dust and then dried to surface dry condition. The required properties of aggregates, was determined by following to IS: 383-1970. Specific gravity of coarse aggregates was determined as 2.65 and it was grey in color.

Water

Water is an important constituent of concrete as it is responsible for chemical reaction with cement. Due to its importance, mixing and curing water should not contain undesirable organic substances or inorganic constituents in excessive proportions. In this project clean potable water was used for both mixing and curing of concrete. It was free from organic matter, silt, oil, sugar, chloride and acidic material as per IS: 456-2000.

CBA

CBA is the waste product of coal fired power plant. It is a non combustible material produced after burning of coal in furnace of coal fired thermal power plants. After burning of coal, the clinkers build up and fall to the bottom hopper of the boiler. Thereafter, clinkers are cooled in the water sump before grinding. CBA obtained from Guru Hargobind Thermal Plant (GHTP Lehra Mohabbat) which is located on State Highway No. 12, runs from Bathinda to Barnala. The physical properties of CBA are given in Table 1.

Table 1: Physical properties of Coal Bottom ash

Properties	Natural Sand	Coal Bottom ash
Specific gravity	2.71	1.78
Water absorption	1.21	9.64
Appearance	Brown	Grayish or Shiny Black
Particle shape	Angular and Little bit glassy	Spherical, irregular and porous

LABORATORY TESTING PROGRAM

Mix design and specimen preparation

In this study, five concrete mixes were prepared each with 0.55 water/cement ratio. First mix was designated as control mix (D1), designed as per IS 10262:2009. Then remaining four mixes were prepared by replacing fine aggregates with coal bottom ash (0 to 40% @ increment of 10%). Water content, cement content and coarse aggregates were constant in all five mixes. The remaining detail of mix design per cubic meter of concrete was shown in Table 2.

Table 2: Mix proportions of concrete mixes

Mix	CBA (%)	Cement (Kg/m^3)	Fine Aggregates (Kg/m^3)	CBA (Kg/m^3)	Coarse Aggregates (Kg/m^3)	Water (L/m^3)
D1	0	358.47	731.70	0	1108.08	197.16
D2	10	358.47	658.53	73.17	1108.08	197.16
D3	20	358.47	585.36	146.34	1108.08	197.16
D4	30	358.47	512.19	219.51	1108.08	197.16
D5	40	358.47	439.02	292.68	1108.08	197.16

Concrete cubes of sizes 100mm x 100mm x 100mm were cast for each mix. Three samples were used for each testing condition, and total numbers of cube specimens were sixty.

Workability of concrete

Slump test was employed to assess the workability characteristics of fresh concrete. The results show that workability of concrete mixtures decreased with the increase in levels of sand replacement with coal bottom ash.

Compressive Strength of concrete

All the cube samples were cured for 28 days prior to heating. The hardened concrete cubes were then dried at room temperature for two hours and then transferred to the muffle furnace. They were heated from room temperature to 150^0C, 300^0C and 600^0C for two and half hour to achieve a uniform temperature distribution across them. After that furnace was turned off and samples were cooled to room temperature. All cooled specimens subjected to compression test under digital Universal Testing Machine (UTM) of 9000kN capacity as per IS 516-1959. A loading rate of 5kN/s was used during testing.

RESULTS AND DISCUSSION

Workability

Workability of concrete mixtures decreased with the increase in percentage replacement of sand with CBA. The slump values decreased from 110 mm to 60 mm when 40% of sand was replaced by CBA as given in Table 3 and illustrated by Figure 1. The reason behind

Table 3: Slump values of concrete

Mix	CBA (%)	Slump (mm)
D1	0	110
D2	10	100
D3	20	92
D4	30	75
D5	40	60

the poor workability characteristics of CBA concrete is the porous structure of CBA. Due to this porous structure, the water absorption (9.64%) of coal bottom ash becomes much higher than the river sand (1.21). Therefore, concrete quickly absorbed water during mixing process which results into reduction of free water content. Moreover, irregular shape and rough texture of CBA particles also increases the inter particle friction. These are the prime factors which contributed in lowering the slump values. The workability characteristics of the coal bottom ash concrete mixes can be enhance with the application of super plasticizers.

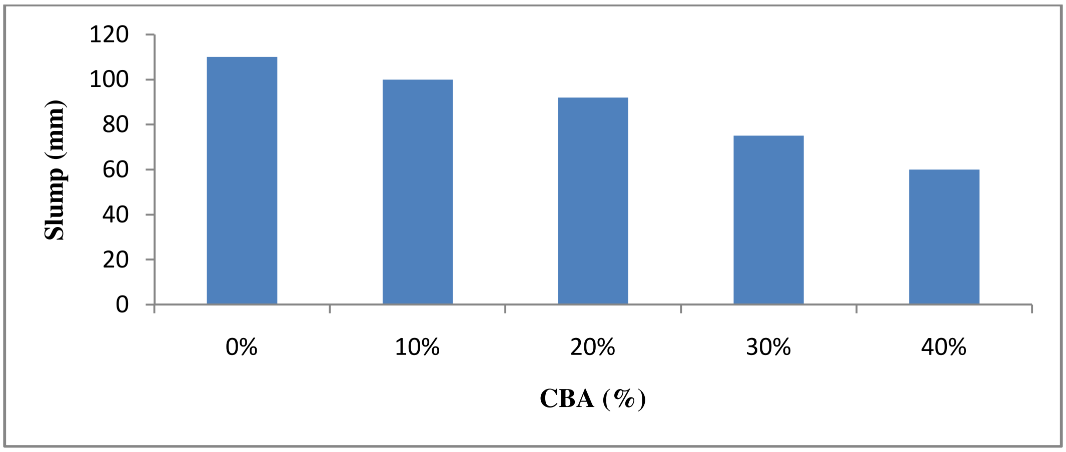

Figure 1: Slump values of concrete mixtures

Compressive Strength

The residual compressive strength of all concretes mixtures at Room Temperature (R.T) and after heating to150^{0}C, 300^{0}C and 600^{0}C is given in Table 3 and illustrated by Figure 2. The percentage loss in strength is given in Table 4 and relative compressive strength is presented by Figure 3. These Tables and Figures clearly show that the compressive strength of all concrete mixtures decreases at elevated temperature. According to the results obtained from present investigation, the strength of concrete with 0% bottom ash after heated to150 ^{0}C, 300 ^{0}C and 600 ^{0}C was 88.9%, 81.9%, and 40.3% of its unheated strength respectively. Almost similarly trend was observed in bottom ash concrete mixtures also. The concrete containing 30% bottom ash exhibited greatest loss in strength, about 12.8% and 21.9% of its unheated strength when heated to150^{0}C, 300^{0}C respectively. The relative strengths of D1, D2, D3, D4 and D5 concretes after heated to 600 ^{0}C were 40.3%, 40.7%, 38.2%, 43.8% and 43.4% of the initial strength, respectively. After the evaporation of physically and chemically bound water, a pressure is build-up which results into the extensive inner cracking. This inner cracking is the main reason for reduction in strength of all concrete mixtures. Apart from it, the cement paste contracts and aggregate expands due to loss of water at higher temperature which leads to loss of the bond between paste and aggregates.

Table 4: Compressive strength of concrete mixtures at different temperature range

Mix	Compressive strength (N/mm^2)			
	Room Temperature (R.T)	150^0	300^0	600^0
D1	29.85	26.54	24.45	12.03
D2	29.14	26.15	23.11	11.86
D3	28.41	25.71	23.21	10.85
D4	27.82	24.26	21.73	12.19
D5	27.04	24.15	21.74	11.74

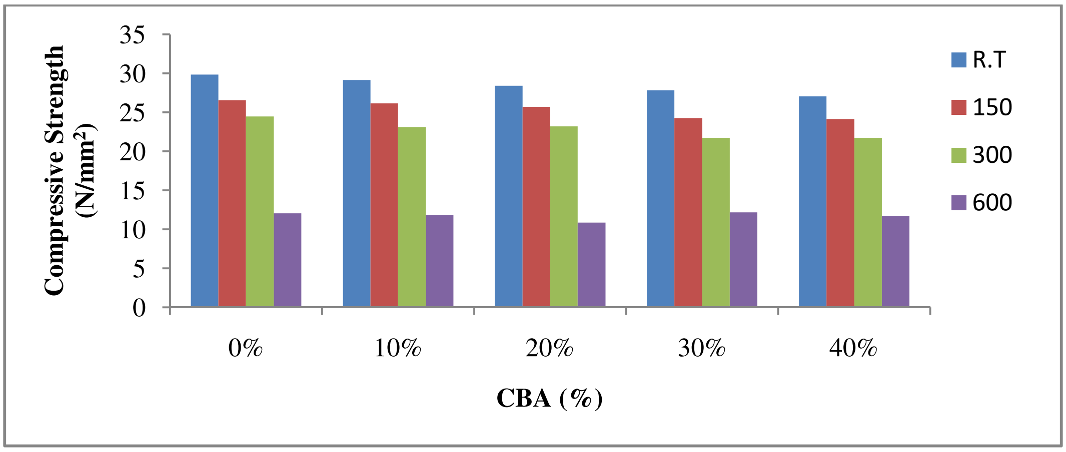

Figure 2: Compressive strength of concrete mixes at different temperature range

Table 5: Percentage loss in compressive strength at different temperature range

Mix	Percentage loss in compressive strength		
	R.T - 150^0	R.T - 300^0	R.T - 600^0
D1	11.1	18.1	59.7
D2	10.3	20.7	59.3
D3	9.5	18.3	61.8
D4	12.8	21.9	56.2
D5	10.7	19.6	56.6

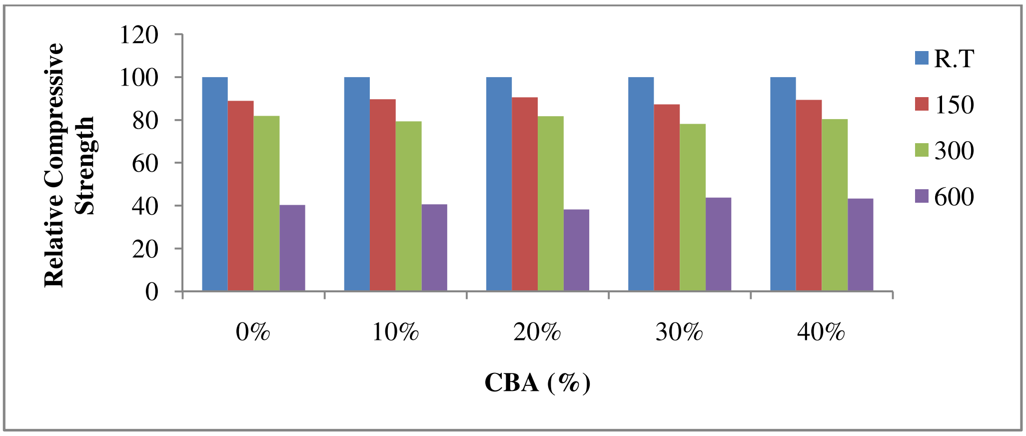

Figure 3: Relative strength of concrete mixes at different temperature range

CONCLUSIONS

The following conclusions can be drawn from this study:

- The compressive strength of concrete with or without CBA decreases with increasing temperature so both are almost equally sensitive to higher temperature.
- It has been observed that the samples produced by replacing 30% of fine aggregates with coal bottom ash exhibit greatest loss in strength when heated up-to 150^0C or 300^0C while concrete with 20% replacement of fine aggregates shows greatest loss when heated at 600^0C.
- Based on the results, it can be concluded that the replacement of fine aggregates with CBA cannot change the strength properties of concrete during heating.

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