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Sustainable Management of Sugarcane Bagasse Ash and Coal Bottom Ash in Concrete

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ABSTRACT

The production of cement involves a large amount of CO_2 emission which has a significant impact on environment. Apart from it, excessive extraction of natural aggregates and large generation of industrial as well as agricultural waste also leads to environmental degradation, ecological imbalance and environmental pollution. Nowadays, utilization of these wastes has been encouraged in concrete construction because it helps in reducing the use of natural raw materials as resources. Therefore, the present study focuses on investigating the effect of sugarcane bagasse ash (SCBA) as a replacement of cement and coal bottom ash (CBA) as replacement of fine aggregates in concrete. This study primarily deals with the characteristics of concrete, including strength and workability. Twenty five mixtures of concrete were prepared at different replacement levels of SCBA (0 to 20% @ increment of 5%) with cement and CBA (0 to 40% @ increment of 10%) with fine aggregates. Based on the test result, it can be concluded that as combination, 10% SCBA and 10% CBA, is recommended for higher workability and strength characteristics of concrete than the control or reference concrete.

INTRODUCTION

Concrete is the world's most consumed construction material because of its excellent mechanical and durability properties. At present, the construction industry is cursed with the scarcity of the aggregates and environmental pollution during the cement production. The cement industry has a significant contribution to global warming because combustion of fuel in the cement kiln and the electricity used for grinding the clinker, emit large amount of CO_2. Cement industry is responsible for about of 5% of global anthropogenic CO_2 emissions (Worrell et al. 2001). Furthermore, the natural resources of aggregates are getting depleted gradually due to the development in infrastructure all around the world. The ban on mining in some areas is further increasing the problem of availability of natural aggregates. Therefore, it becomes essential and more significant to find out the substitutes for both cement as well as natural aggregates. Apart from it, the appropriate utilization of agro and industrial waste is also a basic objective of the sustainable development. However, this objective can be fulfilled by the use of these wastes in concrete upto some extent.

Sugarcane is one of the major crops grown in over 110 countries. The fibrous matter that remains after crushing and juice extraction of sugarcane is known as bagasse. Nowadays, this bagasse is reutilized as a biomass fuel in boilers for vapour and power generation in sugar mills. When this bagasse is burnt under controlled temperature, it results into ash. The resulting ash contains high levels of SiO_2 and Al_2O_3, enabling its use as a supplementary cementitious material (SCM). The use of sugarcane bagasse ash (SCBA) as SCM not only reduce the production of cement which is responsible for high energy consumption and carbon emission, but also can improve the compressive strength of cement based materials like concrete and mortar (Janjaturaphan & Wanson 2010).

Coal bottom ash (CBA) is a non combustible material, produced after burning of coal in furnaces of coal fired thermal plant. No doubt, large amount of fly ash is used in cement production, but CBA is still not used in any form. So this unutilized ash has to be disposed off either dry or wet to an open area near the plant or mix it with water and pump into the water bodies, which causes pollution. 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 & Siddique 2014). To overcome the problem of pollution, it is very necessary to utilize this ash. In addition, CBA has many physical properties which make it attractive to be used as fine aggregates in production of concrete.

Several researchers have investigated the individual effect on the strength properties of concrete by replacing either cement with SCBA or fine aggregates with CBA. The information available on the performance of concrete using combination of these waste materials is scanty. So, the prime objective of the present research is to make an environment friendly concrete by using the combination of SCBA and

CBA in concrete.

MATERIALS USED

Cement: For the development of this research, ordinary Portland cement (OPC) conformed to IS: 12269:1987 was used. Cement was carefully stored to protect from moisture. Compressive strength test, consistency test, setting time test and specific gravity test were conducted to obtain some physical properties of cement. The results of these tests are given in Table 1.

Fine aggregates: Locally available river bed sand, conformed to the requirements of IS: 383-1970, was used as fine aggregates. It was brown in colour, collected from Chakki River (Pathankot). Some appropriate tests were conducted to obtain some required physical properties of the fine aggregates for concrete mix proportioning. These tests were conducted by following the guidelines of IS: 2386-1963. Specific gravity of fine aggregates was determined as 2.71. The sieve analysis of fine aggregates is given in Table 2. It was conformed to grading zone II.

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, were determined by conducting some tests, conforming to IS: 2386-1963. Specific gravity of coarse aggregates was determined as 2.64 and it was grey in colour.

Water: Water is an important constituent of concrete as it is responsible for the 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.

Sugarcane bagasse ash: Sugarcane bagasse ash is produced when bagasse is reutilized as a biomass fuel in boilers for vapour and power generation in sugar mills. When this bagasse is burnt under controlled temperature, it results into ash. The resulting ash has finer sizes, angular shape and rough texture which gives filler effect (physical effect), while the high content of SiO_2 enhances the chemical effect to improve the compressive strength of SCBA concrete (Srinivasan & Sathiya 2010). Bagasse ash was collected from the boiler of a sugar mill situated at village Budhewal. The collection of the ash was carried out during the boiler cleaning operation throughout the three months.

Coal bottom ash: Coal bottom ash 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, the clinkers are cooled in the water sump before grinding. The

Table 1: Properties of OPC 43 grade cement.

Sr. No.	Properties	Values obtained	Values specified by IS: 8112-1989
1	Specific gravity	3.15	-
2	Standard consistency	31	-
3	Initial setting time	135	30 Minute (Minimum)
4	Final setting time	220	600 Minute (Maximum)
5	Compressive strength		
	3 Days	25.54 N/mm^2	23 N/mm^2
	7 Days	36.12 N/mm^2	33 N/mm^2
	28 Days	49.53 N/mm^2	43 N/mm^2

Table 2: Sieve analysis of fine aggregates (total weight of sample = 500g).

IS-Sieve Designation	Weight Retained on Sieve (g)	Percentage Weight Retained on sieve	Cumulative Percentage Weight Retained on sieve	Percentage passing	Percentage passing for Grading Zone-2 as per IS: 383-1970
10 mm	Nil	Nil	Nil	100	100
4.74 mm	42	8.40	8.40	91.60	90-100
2.36 mm	24	4.80	13.20	86.80	75-100
1.18 mm	70	14.00	27.20	72.80	55-90
600 micron	106	21.20	48.40	51.60	35-55
300 micron	121	24.20	72.60	27.40	8-30
150 micron	125	25.00	97.60	2.40	0-10

Table 3: 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

CBA is composed of mainly silica, alumina and iron with small amount of calcium, magnesium sulphate etc. (Singh & Siddique 2014). It is well graded and majority of its grain sizes lies between 4.75 mm to 0.6 mm which are within the limit given by IS: 383-1970 (Kadam & Patil 2013). Coal bottom ash 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 coal bottom ash are given in Table 3.

LABORATORY TESTING PROGRAM

Mix design and sample preparation: The mix proportion selected for this study is given in Table 4. Twenty five concrete mixes were prepared each with 0.55 water/cement ratio. The first mix was designated as control mix (D1), designed as per IS 10262:2009. The remaining mixes were prepared by replacing cement with SCBA (0 to 20% @ increment of 5%) and fine aggregates with CBA (0 to 40% @ increment of 10%). Water content, cement content and coarse aggregates were constant in all mixes. In this study, cubes of sizes 150 mm were casted.

Workability of concrete: In fresh condition, workability characteristics for high quality concrete should be acceptable (around 100 mm slump height). The desired strength of concrete can only be obtained if fresh concrete has adequate slump value. In the present study, workability of each mix was measured in terms of slump.

Compressive strength of concrete: In determining the effect of addition of SCBA and CBA on compressive strength of concrete, a compression test was done by subjecting cube under a digital Universal Testing Machine (UTM) of 9000 kN capacity as per IS 516-1959. The samples were cured under water for a period of 14, 28 and 56 days.

RESULTS AND DISCUSSION

Workability: Workability of concrete was tested using slump test apparatus immediately after preparing fresh concrete. The slump values of each mixture are given in Table 5 and presented in Fig. 1. From results, it can be concluded that the workability of concrete mixtures decreased with

Table 4: Mix proportions of concrete mixes.

Mix	SCBA (%)	CBA (%)	Cement (kg/m^3)	SCBA (kg/m^3)	Fine Aggregates (kg/m^3)	CBA (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (L/m^3)
D1	0	0	358.47	0	731.70	0	1108.08	197.16
D2	5	0	340.55	17.92	731.70	0	1108.08	197.16
D3	10	0	322.62	35.85	731.70	0	1108.08	197.16
D4	15	0	304.70	53.77	731.70	0	1108.08	197.16
D5	20	0	286.78	71.69	731.70	0	1108.08	197.16
D6	0	10	358.47	0	658.53	73.17	1108.08	197.16
D7	5	10	340.55	17.92	658.53	73.17	1108.08	197.16
D8	10	10	322.62	35.85	658.53	73.17	1108.08	197.16
D9	15	10	304.70	53.77	658.53	73.17	1108.08	197.16
D10	20	10	286.78	71.69	658.53	73.17	1108.08	197.16
D11	0	20	358.47	0	585.36	146.34	1108.08	197.16
D12	5	20	340.55	17.92	585.36	146.34	1108.08	197.16
D13	10	20	322.62	35.85	585.36	146.34	1108.08	197.16
D14	15	20	304.70	53.77	585.36	146.34	1108.08	197.16
D15	20	20	286.78	71.69	585.36	146.34	1108.08	197.16
D16	0	30	358.47	0	512.19	219.51	1108.08	197.16
D17	5	30	340.55	17.92	512.19	219.51	1108.08	197.16
D18	10	30	322.62	35.85	512.19	219.51	1108.08	197.16
D19	15	30	304.70	53.77	512.19	219.51	1108.08	197.16
D20	20	30	286.78	71.69	512.19	219.51	1108.08	197.16
D21	0	40	358.47	0	439.02	292.68	1108.08	197.16
D22	5	40	340.55	17.92	439.02	292.68	1108.08	197.16
D23	10	40	322.62	35.85	439.02	292.68	1108.08	197.16
D24	15	40	304.70	53.77	439.02	292.68	1108.08	197.16
D25	20	40	286.78	71.69	439.02	292.68	1108.08	197.16

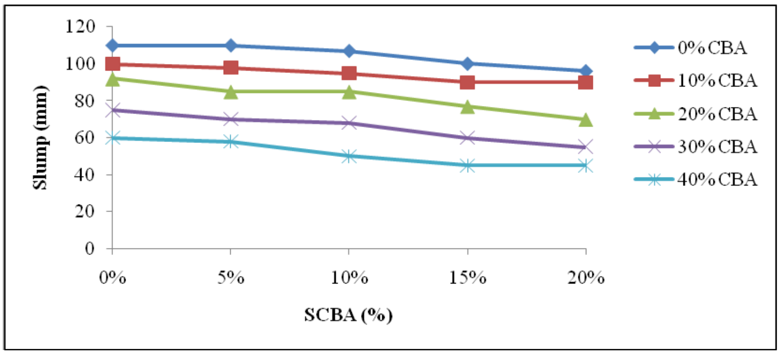

Fig. 1: Slump values of concrete with different replacement levels of SCBA and CBA.

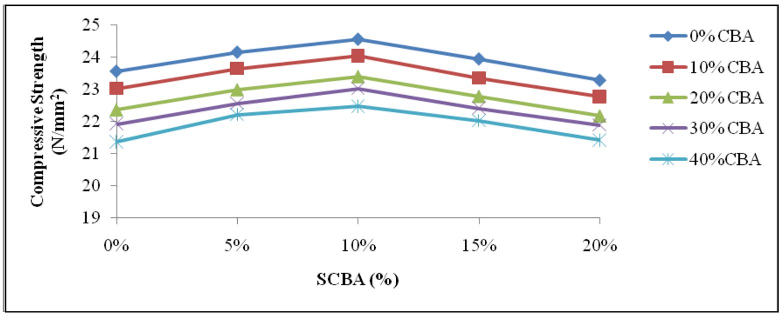

Fig. 2: Compressive strength of 14 days concrete with different replacement levels of SCBA and CBA.

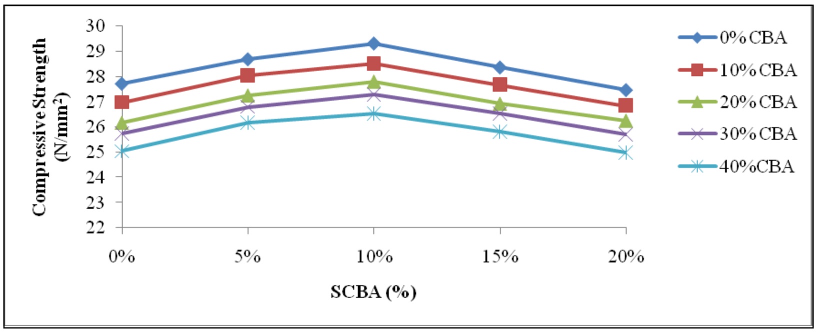

Fig. 3: Compressive strength of 28 days concrete with different replacement levels of SCBA and CBA.

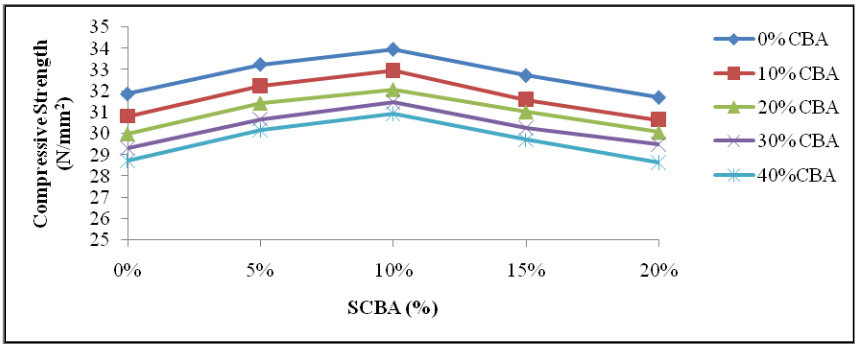

Fig. 4: Compressive strength of 56 days concrete with different replacement levels of SCBA and CBA.

Table 5: Slump values of concrete mixtures.

Mix	SCBA (%)	CBA (%)	Slump Value
D1	0	0	110
D2	5	0	110
D3	10	0	107
D4	15	0	100
D5	20	0	96
D6	0	10	100
D7	5	10	98
D8	10	10	95
D9	15	10	90
D10	20	10	90
D11	0	20	92
D12	5	20	85
D13	10	20	85
D14	15	20	77
D15	20	20	70
D16	0	30	75
D17	5	30	70
D18	10	30	68
D19	15	30	60
D20	20	30	55
D21	0	40	60
D22	5	40	58
D23	10	40	50
D24	15	40	45
D25	20	40	45

Table 6: Test results for average compressive strength of concrete.

Mix	Average compressive strength (N/mm^2)		
	14 Days	28 Days	56 Days
D1	23.57	27.73	31.88
D2	24.16	28.69	33.25
D3	24.56	29.31	33.95
D4	23.95	28.37	32.74
D5	23.29	27.48	31.72
D6	23.03	26.98	30.80
D7	23.66	28.04	32.24
D8	24.06	28.51	32.96
D9	23.36	27.67	31.59
D10	22.77	26.84	30.64
D11	22.37	26.17	29.99
D12	23.00	27.26	31.43
D13	23.41	27.81	32.07
D14	22.79	26.93	31.02
D15	22.18	26.26	30.06
D16	21.94	25.76	29.30
D17	22.58	26.81	30.67
D18	23.03	27.31	31.47
D19	22.42	26.54	30.25
D20	21.90	25.71	29.48
D21	21.38	25.04	28.72
D22	22.23	26.18	30.19
D23	22.49	26.54	30.96
D24	22.04	25.82	29.71
D25	21.43	24.98	28.63

the increase in content of SCBA and CBA. The slump values decreased from 110 mm to 45 mm when 40% of fine aggregates were replaced by CBA and 20% of cement by SCBA. It can be due to the porous structure of CBA's particles which cause the higher water absorption. Due to higher water absorption of particles, the concrete rapidly absorbed water which reduced the free water content of mixture. In addition, rough and angular shape of SCBA's particles increased the inter particle friction which further decreased the slump values of concrete.

Compressive strength: The compressive strength of all concrete mixtures was measured at the age of 14, 28 and 56 days. The results of average compressive strength for different replacement levels of SCBA (0%, 5%, 10%, 15%, and 20%) and CBA (0%, 10%, 20%, 30% and 40%) are given in Table 6. The effect of both waste materials on compressive strength at curing ages of 14, 28 and 56 days is illustrated by Figs. 2, 3 and 4 respectively. It is evident from the Table 6 values that with increasing the SCBA content (upto 15%) the improvement in compressive strength of concrete mixtures is continuous and significant. At the curing age of 14 days, the compressive strength of concrete containing 5%, 10% and 15% SCBA as cement, gained 2.5%, 4.2% and 1.6% as compared to control concrete mixture (D1), while at 20% replacement level the concrete lost 1.2% of strength as given in Table 7. It was also concluded that the gain in compressive strength of SCBA concrete mixtures at curing age of 56 days was more than that of 14 and 28 days of curing. After 56 days of curing, compressive strength of SCBA concrete mixtures exceeded by 4.3%, 6.5% and 2.7% while decreased by 0.5% as compared to control concrete mixture when cement was replaced upto 5%, 10%, 15% and 20% respectively. Nevertheless, the replacement of 15% of SCBA still improves the compressive strength of concrete as compared to the control concrete, but for much better results, the 10% of SCBA seems to be the optimum. This improvement in strength may be due to finer particle size of SCBA, which is filler the effect (physical effect), and high silica content as well as high pozzolanic reaction between calcium hydroxide and reactive silica (chemical effect) in SCBA. On the other hand, there was a significant loss in compressive strength of concrete when fine aggregates replaced with CBA. The incorporation of bottom ash produced relatively low strength concrete as compared to reference concrete due to its porous structure and higher water absorption. The higher water absorption reduced the free water content which interrupted the hydration of cement in concrete. The compressive strength decreases at every replacement level of CBA with fine aggregates. There was no

Table 7: Percentage loss (-) or gain (+) in compressive strength of concrete.

Mix	Percentage loss (-) or gain (+) in compressive strength 14 Days	28 Days	56 Days
D1	0	0	0
D2	+2.5	+3.5	+4.3
D3	+4.2	+5.7	+6.5
D4	+1.6	+2.3	+2.7
D5	-1.2	-0.9	-0.5
D6	-2.3	-2.7	-3.4
D7	+0.4	+1.1	+1.1
D8	+2.1	+2.8	+3.4
D9	-0.9	-0.2	-0.9
D10	-3.4	-3.2	-3.9
D11	-5.1	-5.7	-5.9
D12	-2.4	-1.7	-1.4
D13	-0.7	+0.1	+0.6
D14	-3.4	-2.9	-2.7
D15	-5.9	-5.3	-5.7
D16	-6.9	-7.1	-8.1
D17	-4.2	-3.3	-3.8
D18	-2.3	-1.5	-1.3
D19	-4.9	-4.3	-5.1
D20	-7.1	-7.3	-7.5
D21	-9.1	-9.7	-9.9
D22	-5.7	-5.6	-6.8
D23	-4.6	-4.1	-2.9
D24	-6.5	-6.9	-6.8
D25	-9.1	-9.9	-10.2

improvement in strength at any curing period. As shown in Table 7, the compressive strength of concrete containing 10%, 20%, 30%, and 40% CBA as fine aggregates lost by 2.3%, 5.1%, 6.9%, and 9.1% as compared to control concrete when cured to 14 days. The same trend was observed for the curing period of 28 and 56 days. It can be seen that the loss in compressive strength was minor up to 10% of CBA but beyond 10%, there was a large reduction in compressive strength.

CONCLUSIONS

Looking at the data given in tables and plotted in figures, it can be concluded that, as combination we can replace cement with SCBA upto 15%, while fine aggregates with CBA upto 10% without any loss in the strength of concrete. But, to obtain much better results in strength and workability characteristics as compared to reference concrete, the combination of (10% SCBA + 10% CBA) is recommended. Therefore, the present research spreads the awareness towards the use of these waste materials in concrete, which provides potential environmental as well as economic benefits to concrete industries.

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