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EXPERIMENTAL INVESTIGATION OF SUSTAINABLE CONCRETE SLENDER BEAM UTILIZING FINE COAL BOTTOM ASH AND GROUNDED COIR FIBRE

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Abstract

The current study represents an attempt made to develop eco-friendly structural concrete using different percentages of fine coal bottom ash (FCBA) as a partial cement replacement and grounded coir fiber (GCF) as filler. X-ray diffraction (XRD and key testing were performed to investigate the chemical composition, workability, and splitting tensile strength of the slender concrete beam. The XRD outcomes revealed that the optimal addition of FCBA and GCF in mix can significantly mitigate the pozzolanic activities and create binding effect, thus leading to improving splitting tensile strength by 13.61%. The addition of GCF in concrete mix resulted in enhancement effect to improve the workability of the developed concrete mix by 20.90%. Also, with addition of 10% FCBA and 2% GCF, the flexural strength under four-point bending test showed substantial improvement by 24.50% respectively.

1. Introduction

The construction sector is a massive contributor to climate change, accounting for 42% of human-caused CO_2 emissions [1], [2]. Conventional concrete poses environmental challenges along with increasing global cement because of increasing population also lead to non-recyclable construction waste. To decrease CO_2 emission, construction waste and to mitigate consumption of natural resource usage of alternative materials are much needed [3], [4].

Considering the issue of using unsustainable materials for concrete, Fine coal bottom ash (FCBA) could be utilized as partial replacement to cement, which is the leftover substance obtained when coal is burned in coal-fired fir thermal energy plants. FCBA is a porous, crystalline substance that is often coarse and grey in colour. It varies from fly ash, which are smaller, lighter ash particles that are removed from the environment using electrostatic precipitators [5][6]. Furthermore, part of the ash melts and condenses into clinkers on the steaming tubes and boiler walls. These clinkers eventually gather in the bottom of the boiler or furnace because of steady accumulation [7] [8]. They are subsequently processed through a clinker blender after cooling in a water sump. Moreover, there waste material called coir fibre which is obtained after peeling off coconut that could be utilized to improve toughness and crack resistance of concrete. Also, the fibre as natural fibrous materials can potentially reduce the carbon emission CO_2 [9][10].

2. Materials and Methodology

The chemical characteristics of FCBA can be significantly altered with the type of combustion instances and any substances used in the coal fired plant [11]. Table 1 briefly highlights the chemical characteristics of the FCBA which may help in activating the pozzolanic activities during the chemical reaction of the concrete components. Further, the presence of rich amount of (Ca_2SiO_4) enables the FCBA to be used as a partial or full substitute of conventional ordinary Portland cement (OPC).

Table 1: Chemical characteristics of GCBA

Chemical Characteristics (%)	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]
SO_3	-	1.12	0.81	0.71	0.94	1.06	0.41	0.82
P_2O_5	-	-	0.33	1.22	-	-	0.21	0.66
TiO_2	-	0.99	1.01	-	1.77	2.89	3.81	2.90
CaO	3	0.79	4	12.99	3.22	19.76	22.15	6.21

K_2O	0.076	0.31	1.09	1.05	1.22	2.11	0.34	-
MgO	2.89	0.58	2.57	3.62	1.01	5.01	1.60	1.76
Na2O	3	0.79	4	12.99	3.22	19.76	-	-
Fe_2O_3	7.49	4.91	5.05	12.01	7.99	7.21	-	11.78
Ai_2O_2	23.1	27.31	18.11	22.07	29.65	18.54	28.12	35.09
SiO_2	56.89	57.01	59.79	29.78	49.77	39.54	51.33	-
LOI	3.01	3.89	2.43	-	-	-	4.01	5.22

Several earlier research investigated the use of FCBA as an alternative to OPC, as well as the incorporation of FCBA into the concrete mix with prior adjustment of its dosages. This section presents prior several studies to assess the mechanical characteristics of concrete with the incorporation of FCBA as fine aggregate. The mechanical properties of concretes that incorporated FCBA are presented in Table 2. However, it's worth necessary to identify the suitable dosage of FCBA that can be utilized without compromising the compression and tensile strengths. A recent study reported that after 85 days, at a 12.5% substitution level of fine aggregates with FCBA, the pozzolanic reaction balanced the increased porosity, and the pores' refinement had a positive influence on compressive and tensile strength.

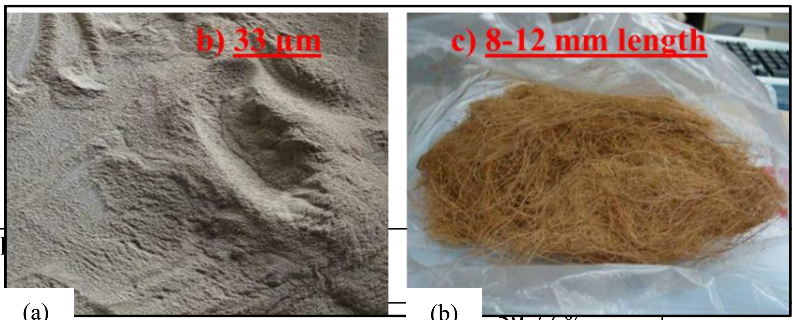
Further investigations on the substitution of volume-based cement with CBA shown, that changes to the combination and component designs used a variety of procedures on CBA, including filtration, thawing, crushing, and the application of a super plasticizer based on Poly- carboxylic acid significantly increased the strength of compression of CBA in mortar [20]. On the other hand, [21] focused on grinding and sulphuric acid impregnation techniques. In cases where the concrete had low strength, the compressive strength decreased by as much as 20 MPa with increasing substitution of cement with CBA. Furthermore, when fully substituting cement with CBA, a maximum decline of 65% was seen contrast to conventional concrete. The improved pozzolanic behaviour of CBA, which may have an adverse effect on compressive strength while outweighing other drawbacks like permeability and porosity. The concrete mix prepared with CBA was investigated by [22] under compression at various mass percentages of sand, including 5%, 10%, 25%, 30%, and 75%. It was revealed that concrete with 28% and 35% CBA displayed considerable benefits both early on and later in the curing process. At 90 days, the mortar mix with 25% CBA outperformed the control mix in terms of strength. At lower substitution levels (15%-19%), compressive strength was higher than in control concrete, but as CBA concentration increased, compressive strength declined. Minor decreases were reported for fine aggregate substitutions of 28% and 39% with coal bottom ash, respectively, a significant reduction was identified for concrete mix with 43% and higher coal bottom ash content.

The effect of curing ages on the concrete mix developed from CBA as OPC substitute was study by [6] and reported that the compressive strength was dropped by a minimum level by by 3%-9% up to 27% CBA, after which it fell further. Similar conclusion was also reported by other scholars where compressive strength declined by 12%-32% with high substitution levels (35%), except in few situations where a 35%-51% rise was recorded [3]. Further, the influence of CBA as sand substitute was reported in different investigations [2], [16], and concluded a decreased in compressive strength by 25%-38% with 74% substitution of CBA. Furthermore, after 56 days of curing, additional research found that the total substitution of natural fine aggregates with CBA resulted in identical compressive strength values. In addition [9] observed a potential 25% increase in split tensile strength when utilising 30% coarser reused concrete particles with 9% average CBA and CF. Similar split tensile strength levels were achieved by concrete compositions including CF, CBA, and 75% recycled concrete particles.

Table 2: Mechanical characteristics of coal bottom ash and other sustainable materials

Ref	(%) Optimized range	Material	Time of curing (Days)	Flexural strength (MPa)	Compressive strength (MPa)
[23]	40	12% Sugarcane Ash	90	7.9	35
[19]	30	3kg/m3 water reducing admixture	28	4.51	32
[24]	20	0.23 w/c ratio and 0.36% SP	40	6.62	38
[25]	10	32% Recycled Concrete Aggregates	180	7.11	60
[11]	40	21% Fine sieved raw coal bottom	365	6.65	80

		ash			



Cl[illegible]	[illegible]	GCBA
Calcium Oxide ([illegible]	59.72 %	4.95%
Silica dioxide *(SiO_2)*	18.95 %	25.41%
Aluminium Oxide (Al_2O_3)	4.12 %	11.12%
Magnesium oxide (MgO)	1.51 %	1.11%
Iron oxide (Fe_2O_3)	2.32 %	5.65%

Figure.1 (a) FCBA (Fine coal bottom ash); (b) Coir Fiber

Table 3. Chemical composition of FCBA and Conventional OPC through XRD test

FCBA as depicted in Figure 1(a) was collected from 70 km north of Hyderabad city from Thar coal power plant. Based on mechanical treatment, the FCBA as shown in Figure 1(a) was obtained in finer form comparable to the OPC and grounded followed by a sieve analysis through a 63 µm sieve.

Xray diffraction test (XRD) was carried out to determine the chemical composition of OPC and GCBA. Particle size distribution distributions under ACI upper and lower limits were performed to achieve the uniform grading and homogeneous sizes of coarse and fine aggregate as illustrated in Table 3. Table 4 shows the mix design proportion of OPC, GCBA, GCF, Fine and coarse aggregate. Figure 2 illustrate the experimental arrangement for testing fabricated slender beam under three point splitting tensile test.

Specimen		FCBA	OPC	FA	CA	Water	GCF
B1		0	390	780	740	170	15
B2		25	410	740	742	170	10
B3		49	418	800	760	170	15
B4		74	425	850	760	170	20
B5		99	450	900	760	170	25

Table 4. Mix Proportioning of different formulations

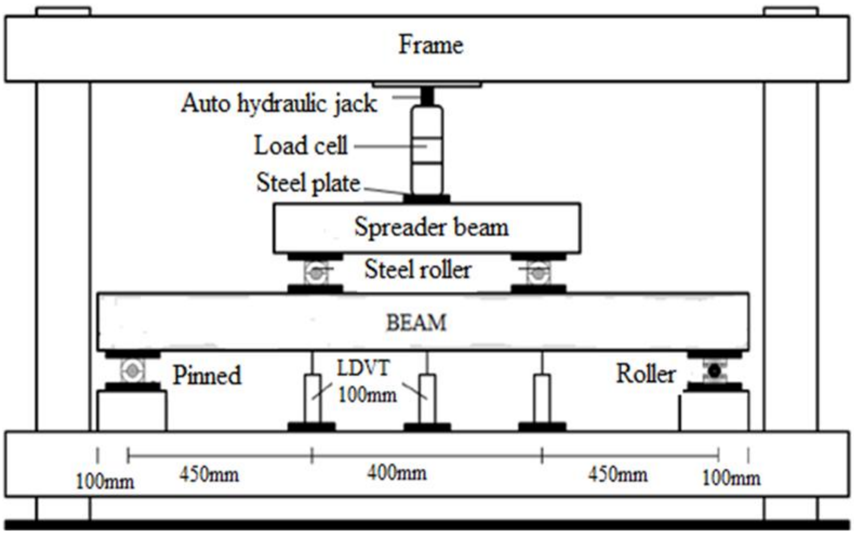


Figure 2: Experimental setup for flexural test

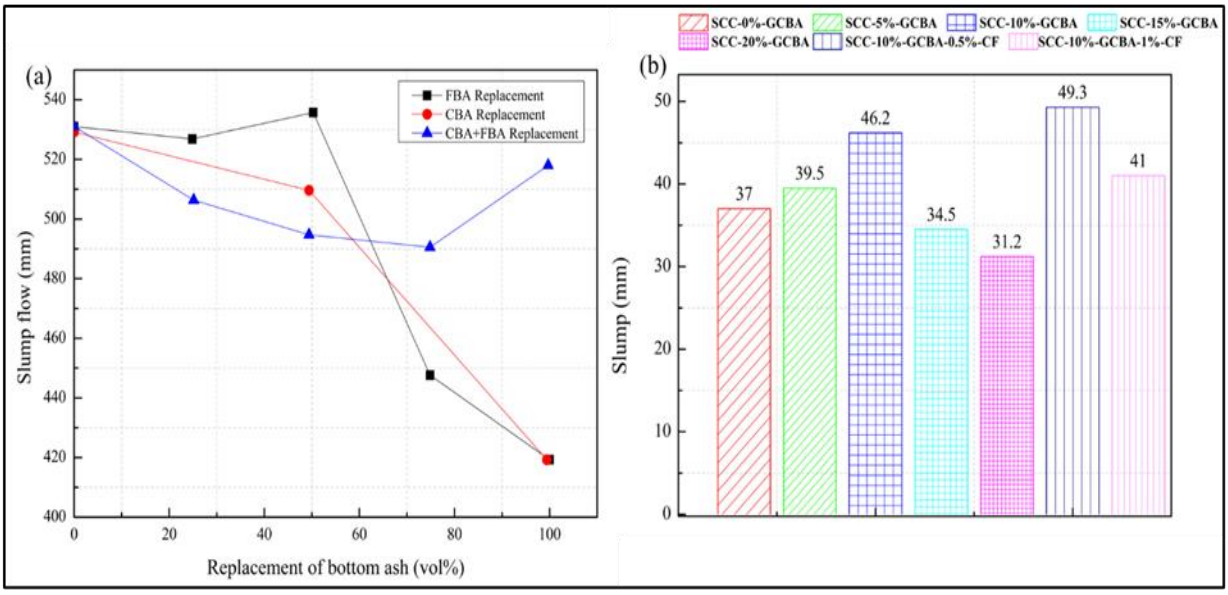


Figure 3: Fresh state properties of the developed concrete mix design; (a) FCBA impact on the flow properties of newly poured concrete; (b) Slump values with different composition of FCBA and OPC.

The workability of the concrete mixture was investigated using slump test, values for the various mixes are presented in Figure 3. The flow ability of concrete matrix was significantly reduced with the separate addition of fine coal bottom ash (FCBA) and coarse bottom ash (GCBA). However, the binary addition of FCBA and GCBA showed enhancement effect on the slump values of concrete mix under different replacement levels. The study revealed that the flow ability of concrete improved.

Figure 4 shows the indirect tensile strength the developed concrete incorporated with FCBA and GCF. The binary blended materials can significantly enhance the durability performance of the developed concrete under standard curing conditions as illustrated in Figure 5. It was reported that the reference specimen achieved 5.20 MPa indirect tensile strength at 28 days water curing.

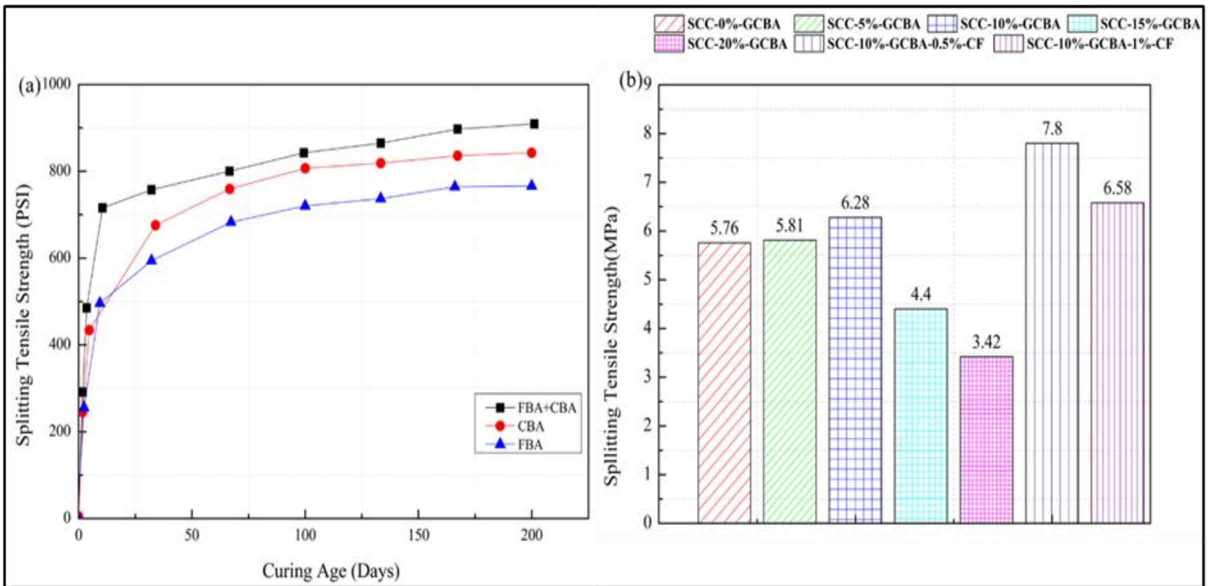


Figure 4: Relationship between curing age verses tensile strength of specimens; (a) Effect of curing age on splitting tensile strength; (b) Splitting tensile strength of different concrete matrixes.

3. Conclusion

This study conducted experiments to predict the key mechanical performance, structural arrangement and chemical characteristics of the developed concrete mixes incorporated with FCBA and GCF. The following conclusions are drawn:

1- The optimum dispersion of FCBA and GCF in aqueous solution was achieved by thirty minutes (30-min) dispersion period with a rotatory speed of 40 rpm.

2- The addition of 15% CF showed enhancement effect to improve the workability of the developed concrete mix design by 20.90% than that of reference concrete mix.

3- Based on FESEM and XRD analysis, the incorporated GCBA up to 40% in concrete mix speed up the pozzolanic activities, thus leading to improve the splitting tensile strength by 13.61%, respectively. However, there was a negative effect on the mechanical strengths of concrete mix observed with the addition of GCBA greater than 10%.

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