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Investigation on Mechanical and Durability properties of Silica Fume blended cement concrete with Coal Bottom Ash as Fine Aggregate

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Abstract:

Concrete is the most widely used substance worldwide it consumes a large number of raw materials and has a detrimental influence on the environment. Using leftover resources from manufacturing industries as a concrete material lessens its need to consume natural resources and promotes safer trash disposal. This study examined the mechanical and durability performance of concrete by substituting 20%,30%,40%,50% and 60% of fine aggregates weight with Coal Bottom Ash (CBA), replacing 12.5% of the cement weight with Silica Fume (SF). Compressive strength, split tensile and flexural strength test were performed for mechanical properties while sulphate attack, sorptivity and carbonation depth test were performed for durability performance. A sequence of 35 concrete cubes were casted, comprising a control mix and mixes that contained CBA and SF. Workability was kept constant by adjusting the dose of superplasticizer with fixed w/c ratio for the mixes containing CBA and SF to maintain the workability value achieved in the control mix. The addition of 12.5% SF and 40% CBA yielded optimal compressive strength, while 30% CBA achieved the best split tensile and flexural strengths. Compared to the control mix, the use of these byproducts improved resistance to sulphate attack, carbonation depth and sorptivity test.

Keywords — **Coal Bottom Ash, Silica Fume, Mechanical and Durability performance**

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I. INTRODUCTION

Concrete is one of the most important materials in building construction and other infrastructure works. It is anticipated that the need for concrete will increase further to almost 7.5 billion m3 (about 18 billion tons) a year by 2050.Such an enormous utilization of concrete calls for higher use of natural aggregates and cement, thus taking toll on the environment. At least three-quarters of the total volume of concrete consists of coarse and fine aggregates [1]. Prohibitions against mining in some areas and growing environmental protection demands complicate the availability of river sand. Sustainability-related problems for sustainable development result from this. Thus, in order to preserve natural resources, it is the responsibility of concrete researchers to identify appropriate substitute materials. Replacement materials that are derived from renewable resources may benefit sustainability and the building sector alike. Given this, numerous researchers have attempted to add to or replace existing components in concrete with materials derived from household, industrial, and agricultural wastes [2].

In electricity power generation plants, which produce a huge amount of CBA and FA as waste products of around about 20–80%, using both the materials in the making of concrete can surely reduce the problem of not only disposal, but also in saving the environment. Coal bottom ash is a by-product of combustion of pulverized coal. In India, Coal fired thermal power plants are the backbone of power supply system and fulfill about 65% country's electricity requirements. 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 [3]. Coal bottom ash removed from the furnace bed accounts for about 20% and is sluiced to the water tank and then pumped out in suspension into lagoons spread over thousand acres of land where the same settles down, decantation takes place and ash dries up. The stockpiled mounds of coal bottom ash on open land pose health hazards to the surrounding environment. Indian coal bottom ash has not been scientifically investigated and as such not been utilized in any form. Appreciating the environmental problems posed by the traditional method of disposal of coal bottom ash, scientific investigation to explore its possible uses is the need of hour. The investigations specifically focused on pozzolanic properties of coal bottom ash indicate that although coal bottom ash has low pozzolanic properties but it is suitable for use in concrete [4].H.K.Kim and H.K.Lee concluded that the utilization of bottom ash in civil engineering is one of the most promising options to reduce, or possible eliminate, the environmental and social problems related to the disposal of coal bottom ash [5]. Coal bottom ash is the suitable material to be used as partial replacement of sand in manufacturing of concrete. Considering workability and strength properties, authors recommend that use of coal bottom ash up to 30% without superplasticizer and up to 50% with superplasticizer in structural concrete. However, 100% coal bottom ash can be used in other concrete applications where workability is not an issue; such as paving blocks, hollow blocks, pavements etc [6].

According to Halan Ganesan from phase I and phase 2 study a substantial increase in compressive strength of 58.3% can be seen when 15% alcoffine is added as a supplementary cementitious material. This results in maintaining the superplasticizer dose throughout the mix but at a higher cost of 8.14% when compared to control concrete. This is necessary in order to incorporate large amount of CBA as fine aggregate [7].

The active SF normally increases strength, while the low pozzolanic reactivity of FA usually reduces the strength qualities, especially the early strength. GBFS typically decreases early strength while having little effect on post-strength; this effect is depending on the water-cement ratio and amount of admixture. The adsorption of CaCO3 on Ca2+ in LP will hasten cement hydration and enhance the early strength development [8].

Yuanfeng Lou and Kaffayattula Khan experimented and found that the addition of SF had an inconsistent effect on the workability of cementitious materials. The majority of the literature claimed that because SF has a bigger surface area than other materials, the mix's workability decreased. However, because spherical shape SF has a water-reducing impact, several tests found that adding SF increased the mix's workability. Therefore, additional research is required to determine how the SF addition affects cementitious mixture workability. When employed in cementitious composites up to an ideal percentage (15–25 percent of cement), SF has a good effect on the properties of strength and durability. Strength and durability have improved due to the physical and chemical activities of SF [9].

Therefore, keeping the above issues and conclusion in mind workability was kept constant by adjusting the dose of superplasticizer with the fixed w/c ratio. As for cost control other Supplementary Cementitious Materials (SCM's) from industrial wastes such as SF is used as a mineral admixture instead of alcoffine to study the performance. A very few studies have been done with SF as cementitious material with CBA as fine aggregate. The objective of this research is to study and to improve the strength and durability performance with these waste byproducts which not only lessens the need to consume natural resources but also promotes a way to safer trash disposal.

II. LITERATURE REVIEW

Halan Ganesan and Abhishek Sachdeva (2023) conducted an investigation in two phases. In Phase I, five percentages (10%, 20%, 30%, 40%, and 50%) of coal bottom ash (CBA) were used to partially substitute fine aggregates in a control mix made of basic concrete materials. Phase II examined the impact of using alcoffine in place of 5%,10%,15% and 20% cement. It is observed that by increasing the amount of alcoffine in the MB4 mix, a smaller dose of superplasticizer is needed to reach the 100 mm slump value. At a superplasticizer dose of ≈1.9%, a slump value of 100 mm was attained for the concrete mixes MB4A15 and MB4A20. This suggests that the MB4A15 and MB4A20 concrete mixes can achieve the required workability of the concrete by adding Alccofine at a fixed water/cement ratio of 0.38 and a superplasticizer dose of less than 2%. This is caused by the cementitious material's ultra-fine size and dense packing, which fills the spaces left by the coal bottom ash concrete mix, or MB4 mix. From phase 1 and phase 2 they concluded that a substantial increase in compressive strength of 58.3% can be seen when 15% alcoffine is added as a supplementary cementitious material. This results in maintaining the superplasticizer dose throughout the mix, but at a higher cost of 8.4% when compared to control concrete. This is necessary in order to incorporate large amount of coal bottom ash as fine aggregate.

Taraq Ali and Abdul Salam Buller (2021) concluded that the 30% CBA replacement as a fine aggregate along with 12.5% SF as a cement replacement achieved the maximum compressive strength 38.45 Mpa, which is almost 21% greater than the conventional concrete and suggested that instead of using a constant water/binder ratio for making CBA concrete, a continuous slump should be taken into account. Due to the fact that CBA absorbs more water than sand, the workability of the final concrete reduced as the contents of CBA and SF increased. It is advised that to study the mechanical and durability performance of concrete containing CBA and SF were tested by maintaining a constant slump with varying water to binder ratios to determine if strength improvements could be achieved and its performance is compared with the control mix and due to its low carbon content, SF serves as an additional binder component during the concrete hardening process and helps to produce a high-quality pozzolanic reaction and also has better durability performance compared to the conventional concrete.

III. METHODOLOGY

An experimental program was planned by collecting the materials required for the study. Preliminary tests were conducted, and a mix design for M30 grade concrete was developed. Six different mixes were prepared: one with control concrete and five with coal bottom ash partially replacing fine aggregate at percentages of 20%, 30%, 40%, 50%, and 60%. These mixes were tested for compressive strength, split tensile strength and flexural strength i.e. the mechanical performance of concrete after 7,28 and 56 days of curing. Slump test was conducted to determine the workability of concrete and for durability performance sulphate attack, sorptivity and carbonation depth test were conducted.

IV. MATERIALS AND ITS PROPERTIES

A. Cement

Cement used in this experiment is OPC 53 grade cement conforming to IS 8112:1989. The physical properties of cement are shown in Table I.

TABLE.I PHYSICAL PROPERTIES OF CEMENT

S. No	Tests performed	Results

1	Standard Consistent value	31 percentage
2	Initial Setting time	42 minutes
3	Final Setting time	510 minutes
4	Specific Gravity	3.15
5	Fineness (<90 microns)	2 percentage
6	Soundness test	1.6mm expansion

B. Coal Bottom Ash

Coal Bottom ash used in this project is from Jerilyn Agencies, Tuticorin and is shown in fig 1. The physical properties of CBA are presented in Table II. The particle size distribution of M sand and CBA is shown in Fig 4.

Fig.1 Coal Bottom Ash

C. Silica Fume

A by-product of the smelting process used in the silicon and ferrosilicon industries is silica fume. It offers higher durability performance, reduces concrete bleeding and segregation, and greatly increases concrete strength. The SF used in this project is brought from Astraa Chemicals, Chennai and is shown in Fig 2.

Fig. 2 Silica Fume

D. Coarse Aggregate

Locally available coarse aggregate of size 20mm conforming to IS:383-1970 was used in this experiment. The physical properties were presented in Table II.

E. M sand

Locally available coarse aggregate of size 20mm conforming to IS:383-1970 was used in this experiment. The physical properties were presented in Table II. The gradation curve of M Sand and Cba is shown in Fig 4.

TABLE.II PHYSICAL PROPERTIES OF CA, CBA, M SAND AND SF

Materials	**Specific gravity**	**Fineness Modulus**
Coarse Aggregate	2.87	7.87
CBA	1.92	2.79
M Sand	2.65	2.96
Silica Fume	2.22	-

F. Superplasticizer

The Super plasticising admixture used in this experiment is Conplast SP430 from Fosroc Chemicals is shown in fig 3. It is added to the mix to ensure adequate fluidity without bleeding or segregation while adjusting the water binder ratio to maintain a steady slump value throughout the mixture.

Fig.3 Conplast SP430

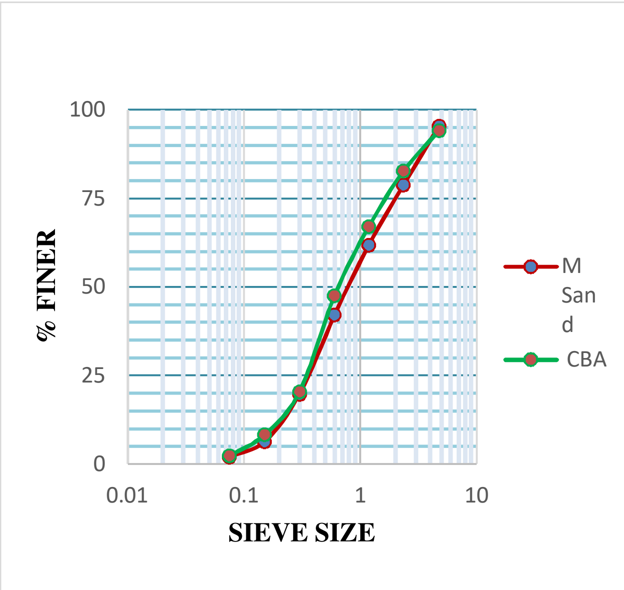

Fig.4 Grading curve of CBA and M sand

G. Mix Proportions

Concrete mix design for Grade M30 was performed as per IS 10262:2019 for the required exposure and consistency classes. The designed slump value is 100mm.Fixed quantities of CA is 1307kg/m^3 and w/c ratio is 0.43 for all concrete compositions. The SF is maintained as 12.5% by weight of cement throughout the replacement mixes [3]. The mix composition for the partially replaced material is presented in Table III.

TABLE.III MIX PROPORTIONS

S.No	Mix type	M sand kg/m^3	CBA kg/m^3	SF kg/m^3
1	Control Mix	697	0	0
2	12.5SF20CBA	557.6	139.4	44.87
3	12.5SF30CBA	487.9	209.1	44.87
4	12.5SF40CBA	418.2	278.8	44.87
5	12.5SF50CBA	348.5	348.5	44.87
6	12.5SF60CBA	278.8	418.2	44.87

TABLE.IV SUPERPLASTICIZER DOSAGE TO ACHIEVE A 100MM SLUMP

Mix Type	Required Dosage in (%)
Control mix	0
12.5SF20CBA	1.5
12.5SF30CBA	1.8
12.5SF40CBA	2

Even with higher dosage of superplasticizer, mix 5 and mix 6's workability cannot be maintained, resulting in slump value less than 100mm.

H. Casting and curing of specimen

Concrete cube of size 150mm x150mm x150 mm sizes were cast to determine the compressive strength and durability performance. Cylindrical specimen of size 150 mm diameter and 300 mm height were cast to determine the split tensile strength of concrete.150 mm x 150 mm x 1000 mm beams were casted to determine the flexural strength of concrete as per the guidelines of IS456: 2000.The specimen was demolded after 24 hours and were water cured for 7,28 and 56 days as per the requirement.

Fig 5 Casting and curing of Specimen

I. Testing Procedures

The compressive strength of concrete cube samples was determined by a compressive testing machine as per IS 516:1964 for the water-cured specimen [12]. Both the specimen's surface and the machine's bearing surface were thoroughly cleaned. The specimen's axis was precisely positioned in the loading frame's centre, and the applied load was increased constantly until the specimen failed.

The split tensile strength of the concrete specimen was determined by a compressive testing machine. A series of 24 concrete cylinder specimens, each measuring 300 mm in length and 150 mm in diameter, were tested in a 3000 KN capacity compression testing machine as per IS 516: 1964 [12]. The specimen's axis was precisely positioned in the loading frame's center, and the applied load was increased constantly until the specimen failed.

The beam specimen was subjected to single concentrated loading at mid-span to determine the modulus of rupture, which is the ability to withstand bending due to external force. A series of 24 concrete beam specimens, each measuring 1000 mm in length and 150 mm in depth and width, were absorbed. The water cured beam specimens were tested on 28 and 56 days as per IS 516:1964[12].

V. RESULTS AND DISCUSSIONS

J. Workability test

Workability of concrete by slump cone test is carried out as per IS 1199-2018 [11]. From Table. IV a slump value of 100 mm was intended to be achieved with the controlled concrete mix. By adjusting the superplasticizer dosage experimentally, an effort is made to keep the same slump value and fixed water cement ratio of 0. 43.It is evident that CBA has low specific gravity compared to M sand because coal bottom ash particles absorb water more quickly than river sand particles during mixing, there is less free water available for particle lubrication, which lowers the slump value. The partial substitution of CBA for river sand results in an increase in the specific surface area of fine aggregate [4].

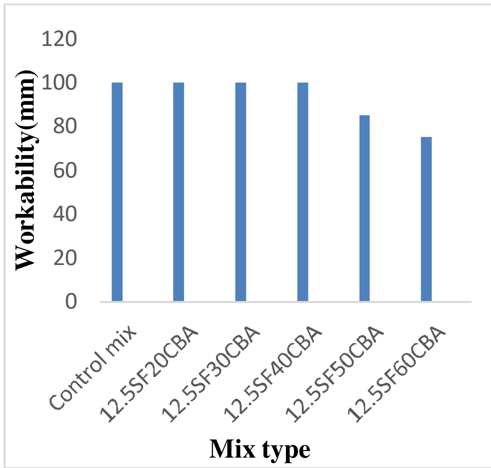

Fig.6 Workability Vs Mix Type

K. Mechanical Properties

1). Compressive Strength of concrete

It is evident that as the replacement percentage of CBA increased, the cube specimen's compressive strength gradually declined. It is possible to detect the abrupt decrease in strength in 50% and 60% CBA replacements. Comparing the performance of the CBA and SF mix, which comprise 30% and 40%, respectively, to conventional concrete, which has a compressive strength value of 33.65N/mm^2, the CBA mix has a value of 39.69N/mm^2 and 43.36N/mm^2. Early age strength is less for bottom ash concrete compare to control mix, but as the age increases, they show good improvement in strength due to pozzolanic reaction [13]. The strength variation in compression strength at different ages of curing is shown in Fig.7

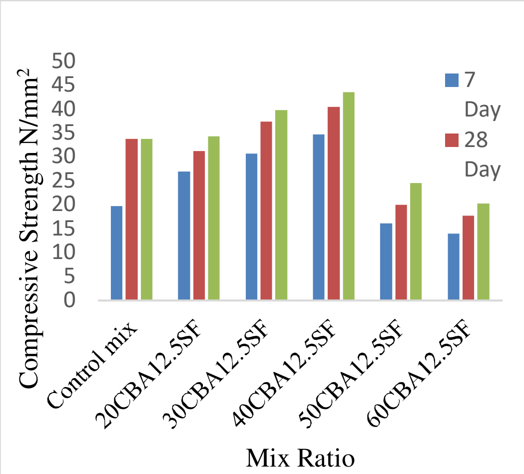

Fig .7 Compressive Strength VS Mix Ratio

2). Split tensile strength

It is evident from Fig.8 that as the replacement percentage of CBA increased, the cylinder specimen's split tensile strength gradually declined. It is possible to detect the abrupt decrease in strength in 50% and 60 % CBA replacements. The strength of the mixes including 12.5 SF and 20CBA, 40CBA is both higher and comparable to standard concrete. The ratio with a 30 CBA attainment has higher overall performance with split tensile value of 4.79N/mm^2.

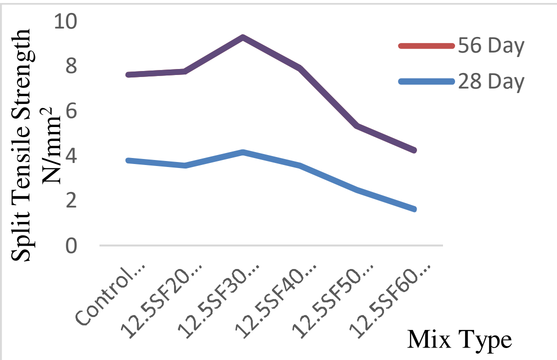

Fig.8 Split Tensile strength VS Mix Type

3). Flexural strength test

It is evident that as the replacement percentage of CBA increased, the beam specimen's flexural strength gradually declined. It is possible to detect the abrupt decrease in strength in 50% and 60% CBA replacements. The ratio with 12.5SF and 30CBA attainment has higher overall performance with flexural strength value of 6.21N/mm^2.The flexural strength value of 30% CBA replacement has somewhat similar performance to that of conventional concrete. The flexural strength variation at different ages of curing is shown in Fig.9.

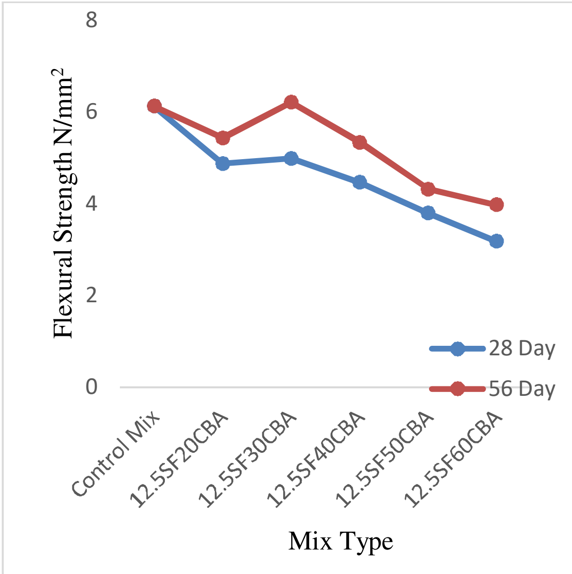

Fig.9 Flexural Strength VS Mix Type

L. Durability Properties

1). Sulphate Attack

Acid resistance is one of the important tests, which is used to evaluate the long-term durability of cement paste/concrete mixtures submersion in a certain acid solution can be calculated to determine the percentage loss [14]. In this experiment, the test is performed using a diluted H_2SO_4 solution and the percentage loss is recorded. For concrete that was replaced with conventional concrete and CBA, the percentage loss is 12.03% and 3.54%, respectively.

Fig.10 Sulphate Attack test

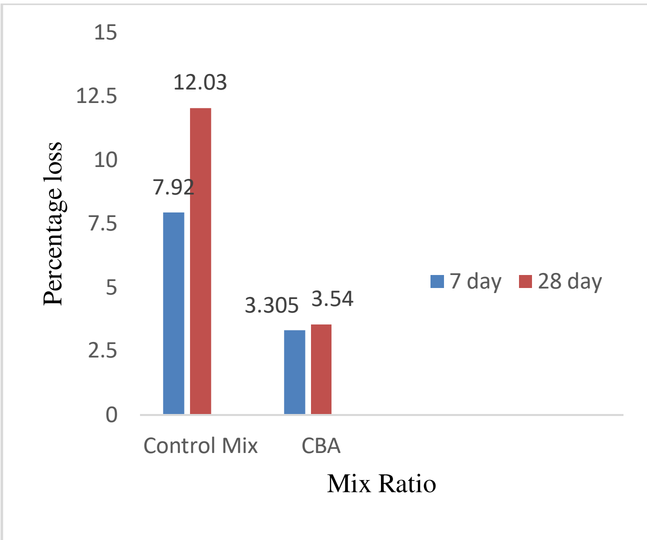

Fig.11 Percentage loss in 7 and 28-days VS Mix Ratio

The graph unequivocally demonstrates that, following 28 days of immersion in acid, the largest percentage loss is noted in conventional concrete as compared to CBA and SF substituted concrete. The lower percentage loss indicates higher resistance to the degradation mechanisms such as freeze and thaw cycles, chemical attack or abrasion.

2). Sorptivity test

Water Sorptivity Index (WSI) test measures the rate of movement of a wetting front through concrete under capillary suction [15].

Fig.12 Sorptivity Test Setup

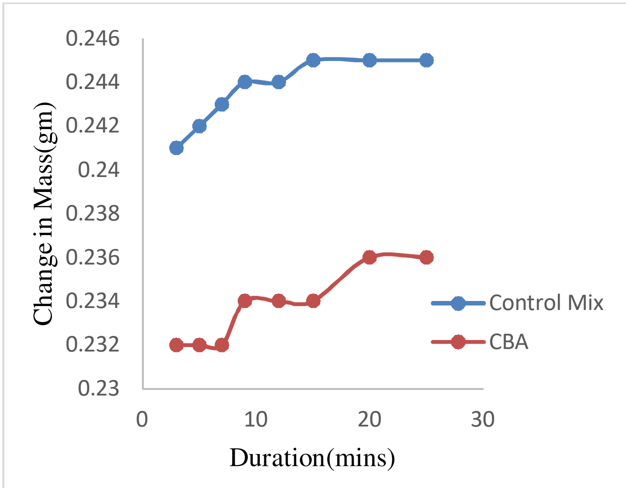

Fig.13 Comparison of capillary action in CBA and conventional concrete

The solid curves in Fig.13 represents the capillary water absorption over time for CBA and conventional concrete sealed with epoxy resin. During testing it was discovered that the concrete can be seen to darken to a certain depth due to water penetration, but the change in mass takes some time to become apparent. It may be due to slow diffusion through concrete matrix or it may be due to initial water retention as it displaces air and darkens the concrete. The mass change is noticeable only after more significant water retention or when water starts evaporating from the concrete, which takes longer.

3). Carbonation Depth

Carbonation depth determines the concrete carbonation resistance by phenolphthalein indicator solution and the test is carried out as per the guidelines of IS-516(Part 5/Sec 3):2021 [16].

Fig.14 Carbonation Depth test in CBA concrete

The Fig.14 clearly state that the test results show no detectable carbonation in the concrete at the 2-month mark as the concrete turns pink upon the application of phenolphthalein, it indicates that the pH of concrete is above 9, the absence of carbonation suggests the concrete has a high-quality mix, low permeability and proper curing which are all the factors that can prevent or significantly delay carbonation.

VI. CONCLUSIONS

Based on the tests and investigations conducted, CBA can be used effectively as a partial replacement for fine aggregate with the addition of SF due to its excellent pozzolanic properties, thereby playing a vital role in strength improvement.

1.As suggested by [4] and [7] maintaining consistent workability throughout the mix by adjusting the dosage of superplasticizer as well as adding mineral admixture to CBA concrete indeed improves compressive strength performance.

2.The optimum compressive strength obtained is from concrete mix containing 12.5SF40CBA which is 28.86% greater than conventional concrete. Optimum split tensile and flexural strength obtained at 12.5SF30CBA.

3.Constant slump cannot be maintained for mixes 5 and 6 due to porous nature of CBA and dosage of superplasticizer is restricted to 2% after that slump value cannot be maintained. Superplasticizer dosage maintained to this extent is due to the presence of SF.

4.Based on sulphate attack test results CBA concrete exhibits superior sulphate resistance compared to conventional concrete.

5.The enhanced durability was attributed by incorporating CBA which likely contributed to a denser microstructure and reduce permeability, thereby improving the concrete's ability to resist external factors that typically lead to material deterioration.

6.In sorptivity test, the visibility water absorption depth on the surface and the delayed mass change can be attributed to the combined effects of slow capillary action, diffusion through concrete mix. This slow process indicates positive aspect for durability.

7.Concrete shows no signs of carbonation at 2 months, which is a strong indicator of its quality and suitability of its intended use. Periodic testing in the future is recommended to ensure that carbonation does not develop over time.

8.The early strength performance was improved by adding silica fume; however, the strength enhancement was not noticeable until 56 days later. It is recommended to use chemical accelerators and pozzolans in to the mix to study the performance.

9.There hasn't been much research on using CBA concrete as a sound absorber in buildings for acoustic purposes.

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