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BROADER USE OF AGRO-FORESTRY-BASED ASH AS A CEMENT REPLACEMENT IN CONCRETE

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Abstract— **Concrete is the most versatile construction material because it can be designed to withstand the harshest environments while taking on the most versatile forms. Engineers are continually pushing the limits to improve its performance with the help of innovative supplementary cementitious materials. Nowadays, most concrete mixture contains supplementary cementitious material which forms part of the cementitious component which has majority of by-products from other processes.**
India generates a significant amount of waste from agricultural and forest-based industries. Similarly, India has lots of sugar cane bagasse waste. Researchers in India want to use these forms of waste in concrete, not only to solve the problem of land filling, but also to use it, if possible, as a supplementary cementing material to reduce the economic and environmental cost of concrete. In the present investigation, a feasibility study is made to examine agro-forest based ashes (soft wood ash + hard wood ash + rice husk ash + sugar cane bagges ash) as supplementary admixtures in concrete. These agro-based ashes are waste generated from pulp and paper mills, typically consisting of a mixture of hardwood and softwood barks and their fine residues. Also, ash resulting from sugar cane bagasse, which is burnt as fuel in sugar mills, has also been investigated as a pozzolanic admixture. Rice husk which is waste generated from the rice industry which used as a fuel in many industries. All of the ash samples were first characterized for chemical composition and physical properties, including grain-size distribution, density and chemical composition. Subsequently, the ash was added to concrete as a supplementary cementing material to study the compressive and tensile etc, performance of hardened concrete. With FBA (Forest based ash) ash, specimens of concrete incorporating different percentages of ash as a mass replacement of Portland cement were subjected to compression and split tensile tests. From the strength point of view, the results are encouraging: for example, when the dosage level of agro-based ashes was as high as 15%, the strength was still seen as promising. The findings strongly endorse that sugar cane bagasse ash imparts resistance to concrete against sulphate Resistance and may be used as a supplementary cementing admixture. Results show that these agro-based ashes can be used in normal-strength concrete buildings.

Keywords— **Forest based ash, compressive strength, flexural strength and Sulphate Resistance**

I. INTRODUCTION

Global movement in worldwide scenario is going to be energy saving and carbon reduction.Currently humanity may be living in an unsustainable manner with respect to its usage of natural resources. Although the supply of natural resources is measurable, the demand for raw materials has increased greatly during past few years. The growing demand for natural resources may cause the causalities such as technological improvements that have made more products available to society, rising affluence levels in the developing world and the overall increase in the overall global population. Another concern about the use of natural resources is the potential generation of CO_2 emissions and their harmful effect on the globe.

Maximum application of resources, efficient and economical construction with quality improvements costs which become urgent issues which promotes overall economic development, strives to improve living standards and solves the problems of shortages in resources. Recycling is accepted to be one of the important bases of sustainability. Now days we are trying to utilize all kind of product, whether they are metal, concrete, plastic, wood, glass or even agro forest will eventually turn into wastes that must be disposed. The best possible way to deal with such kind of wastes is to recycle and reuse them as raw materials or modifiers. This will reduce the drain on the natural resources of the raw materials, and it will reduce the spaces used as landfills. Among all these agriculture is also worldwide used in our daily life by several direct or indirect manners. With the rapid development, higher living standards and higher population growth, the quantities are expected to be sharply increased. The solid waste generation in India is shown in the figure-1.

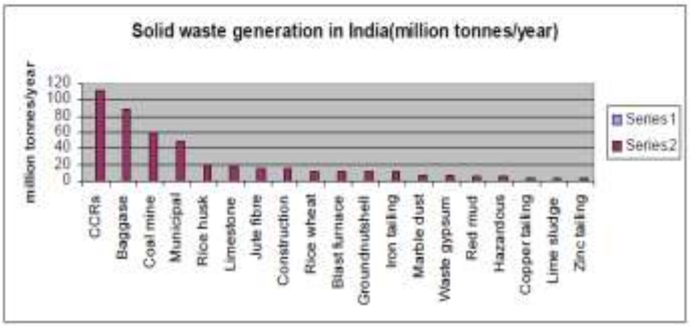


Figure-1. Solid Waste generation in India

II. PAST STUDIES

Chusilp et al. (2009) found that concrete specimens containing 10–30% ground bagasse ash instead of cement in binder had greater compressive strength than the reference concrete (concrete without ground bagasse ash) at 28 days, while the water permeability of this concrete was lower than that of reference concrete. Comparing different percentages, concrete containing 20% ground bagasse ash had the highest compressive strength at 113% of the reference concrete. Radke et al. (2012) found 20% optimum value and discovered that SCBA can potentially be sold at a price similar to that of slag and fly ash, thereby making it cost effective and environmentally friendly. Findings by Chusilp et al. indicate that ground bagasse ash can be used as a pozzolanic material in concrete to have an acceptable strength, lower heat evolution, and reduced water permeability with respect to the control concrete. Srinivasan et al. (2010) have done similar studies on SCBA concrete and concluded that bagasse ash mainly contains aluminum ion and silica. It has been chemically and physically characterized, and partially replaced in the ratio of 0%, 5%, 10%, 15%, 20% and 25% by the weight of cement in concrete. Fresh concrete tests including a compaction factor test and slump test were done, as were hardened concrete tests including compression, splitting tensile and flexural tests at seven and 28 days. The results showed that the strength of concrete increased as the percentage of bagasse ash replacement increased.

Amin (2011) concluded that the specific surface area of bagasse ash is found to be three times higher than that of cement. The density, specific gravity and mean grain size of bagasse ash are found to be less than those of cement. Kawade et al. (2013) found that SCBA made concrete stronger and easier to work with. Muangtong et al. (2013) found that at older ages, the result is observed that the intensity of CH phase decreases whereas that of C-S-H phase increases in the cement replaced with SCBA comparing to without SCBA. Ultra-finely ground SCBA was produced by vibratory grinding resulted in the production of high-performance concrete with 20% replacement instead of Portland cement Fairbairn et al. (2012). The addition of SCBA also resulted in improvements in the rheology of concrete in the fresh state and resistance to the penetration of chloride-ions. Also, Rukzon et al. (2012) noticed an improvement in concrete's resistance to chloride penetration when SCBA was used to enhance the precipitation sites of hydration products and reducing the $Ca(OH)_2$ of concrete. Fairbairn et al. studied the thermal, chemical and mechanical behavior of concrete containing 5 to 20% of ash and discovered the viability of possible CO_2 emissions reductions for cement manufacturing.

Rao et al. studied RHA in concrete under elevated temperatures and found that using RHA in concrete is not only cost effective but also improves resistance against elevated temperatures and durability and reduces carbon dioxide emissions. Harison et al. (2014) investigated the effect of fly ash in concrete on strength of Portland cement concrete. In this study, cement was replaced by fly ash in the range of 0% (without fly ash), 10%, 20%, 30%, 40%, 50% and 60% by mass fraction of the cement. It was observed that using 20% fly ash as a replacement increased the strength marginally (1.9% to 3.2%) at 28 and 56 days respectively. Also, when up to 30% of fly ash is used to replace Portland cement, after 56 days the strength is almost equal to that of the reference concrete.

In the present research, a feasibility study was made to investigate the potential use of forest-based ashes as supplementary admixtures in concrete. The forest-based ashes are waste from wood suppliers, typically a mixture of hardwood and softwood bark, sugar cane industry, forestry waste, and rice husk ash and fines. Chemical and physical tests of XRD, SEM and particle and sieve analysis were conducted to characterize the ash for their different chemical and physical properties and potential pozzolanic activity properties.

Subsequently, the potential to use ash as a pozzolanic admixture was examined by replacing Portland cement with the ash from 0 to 20% by mass at 5% increments. This research is designed to study the short-term mechanical performance and fresh properties of concrete.

III. PROPERTIES OF MATERIALS

This study is based on a feasibility to use forest-based ashes as supplementary admixtures in concrete which are waste generated from burning wood residues, typically consisting of a mixture of hardwood and softwood barks and their fine residues also contains sugar cane bagges ash and Rice Husk ash. In the study reported here, the ash was characterized by chemical composition and physical properties. The chemical and physical characterization of the four different types of ash was done by examining each type of ash for grain-size distribution, density and chemical composition. The results of particle-size analysis show that all the forest based ashes had a mean particle size between 100 and 1000 µ, which is larger than that of the Portland cement used in this study.

A). Forest Based Ash Chemical and Physical Analysis.

Four types of forest-based ashes were studied. In the present study, SEM (Scanning Electron Microscopy), particle and sieve analysis tests were conducted on FBA ash mixtures to determine chemical and physical properties and potential pozzolanic activity. Table -1 gives the various oxides found in the FBA. Further, it was seen that in all cases of ashes (FBA 1 through 4), the chemicals portlandite, arcanite, quartz and calcite exhibited distinct peaks as compared to the other minerals listed in the table below. Table -2 compare all the specimen chemical properties.

Table -1- Chemical composition of forest-based ashes as found using XRD

Arcanite	Sylvine	Moissanite	Hematite
Portlandite	Paragonite	Laumontite	Magnesite
Calcite	Quartz	Anhydrite	Apatite
Muscovite	Siderite		

Table -2- Chemical Composition of Forest Based Ashes

Oxide	FBA1	FBA2	FBA3	FBA4
	Avg. Wt%	Avg. Wt%	Avg. Wt%	Avg. Wt%
Na_2O	2.45	1.92	2.99	
MgO	5.81	3.45	5.21	1.94
Al_2O_3	1.98	2.50	1.78	0.53
SiO_2	11.88	14.31	10.31	2.31
P_2O_5	4.09	3.16	3.06	3.43
SO_3	25.60	28.03	31.02	18.47
K_2O	9.94	13.93	13.24	8.10
CaO	36.00	29.99	29.72	63.03
TiO_2	0.22	0.28	0.19	0.22
MnO	0.18	0.19	0.16	0.24
Fe_2O_3	1.37	1.85	1.25	1.01
Ni_2O_3	0.02	0.01	0.01	
CuO	0.02	0.01	0.01	0.02
ZnO	0.30	0.23	0.39	0.50
Ni_2O_3	0.01	0.01	0.01	0.02
SrO	0.12	0.12	0.11	0.13

SEM was used to study the ashes to observe their particles, particularly their size. Nine particles of FBA 1, 6 particles of FBA 2 and 3 particles of FBA 3 were tested. The particles in FBA 1, FBA 2, FBA 3 and FBA 4 were more than 100 microns and shapes were as follows: FBA 1 particles were spherical and book-structured, FBA 2 particles were pin-like and spongy, FBA 3 particles were spherical, non-spherical and sheet-like and FBA 4 particles were spherical, spongy and book-structured. The shapes of the ash particles are shown in Figure -2, Figure- 3, Figure -4 and Figure -5.

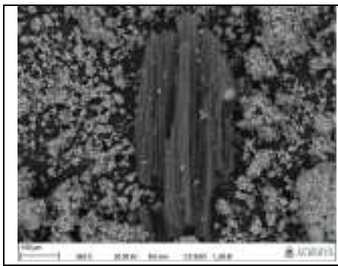
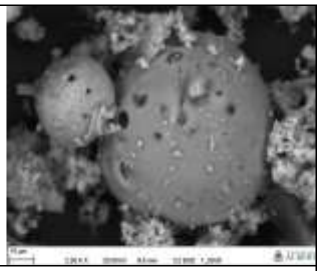


Figure-2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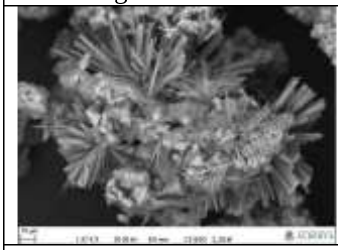
Figure-4

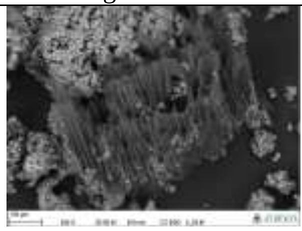
Figure-5

Particle-size analysis of the forest-based ashes was done by Laser diffraction measures particle-size distributions by measuring the angular variation in the intensity of light scattered when a laser beam passes through a dispersed particulate sample as shown in figure-6

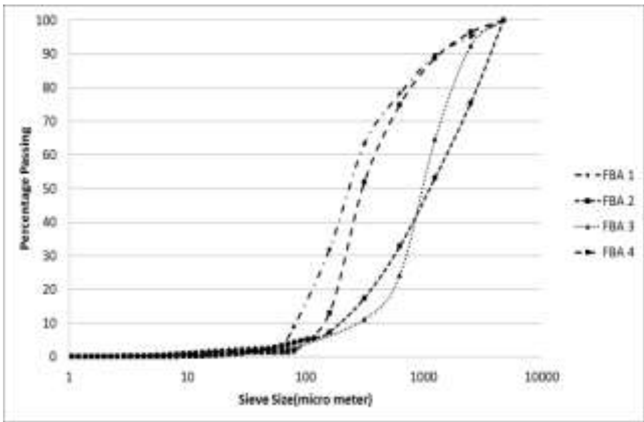

Figure-6, Particle size of all the Specimens

B). Portland Cement

Portland cement is a fine, grey powder. The basic composition of cement is given below in Table-3. Cement is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens.

Table -3, Composition of ordinary Portland cement as per company.

Ingredient	% Content
CaO(Lime)	60-67
SiO_2 (Silica)	17-25
$Al_2\ O_3$(Alumina)	3-8
$Fe_2\ O_3$ (Iron Oxide)	0.5-6
MgO(Magnesia)	0.1-4
Alkalies	0.4-1.3
Sulphur	1-3

In this work Birla Plus of 43grade was used for casting cubes and cylinders for all concrete mixes. The cement was of uniform color i.e. grey with a light greenish shade and was free from any hard lumps. The various tests conducted on cement are initial and final setting time, specific gravity, fineness and compressive strength. The results of Physical Properties of Cement and above said tests are given below in Table - 4 and Table - 5

Table -4 Physical Properties of Cement

Test Conducted	Values Obtained	Standard values
Initial Setting time	28 minutes	Not < 30 minutes
Final Setting time	580 mintues	Not > 600 minutes
Fineness	225	< 225 m^2/kg

Table -5- Compressive strength of cement

Days	Specimen	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
3	1	26	27
	2	29	
	3	27	
7	1	38	36
	2	35	
	3	36	
28	1	43	43
	2	44	
	3	40	

C). Fine Aggregates

The sand used for the work was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was sieved through 4.75 mm sieve. The various other tests conducted are specific density, bulk density, fineness modulus, water absorption and sieve analysis to meet all the requirements of IS 383-1970. The fine aggregated belonged to grading zone II. This Aggregate has absorption of 1.23%. The Bulk Specific Gravity of the fine aggregate was 2.60 while its SSD Specific Gravity was 2.63.F.M of fine sand is 2.28.

D). Coarse Aggregates

The material which is retained on IS sieve no. 4.75 is termed as a coarse aggregate. The crushed stone is generally used as a coarse aggregate. The aggregates were tested as per IS: 383-1970.Coarse aggregate having Fineness Modulus is 7.22

IV. RESULT AND DISCUSSION

A. Compressive strength

Cubes were molded with a 150 X 150 X 150 mm in size to determine the compressive strength of the concrete mixtures. The cubes were tested at 7 and 28 days as per IS 516-1959. Figure -6 shows that the compressive strength of all the specimens at 28 days. Table -6, 7, 8 & 9 provides the compressive strength of concrete for 7 and 28 days for all the FBA specimens.

Table -6 Compressive Strength of FBA 1 Concrete Cube after 7 and 28 Days

Percentage of FBA (%)	Average Compressive strength (N/mm^2) 7th day	Average Compressive strength (N/mm^2) 28th day
0%	16.43	32.01
5%	15.96	32.66
10%	16.88	30.33
15%	18.87	29.98
20%	18.67	27.07

Table-7, Compressive Strength of FBA 2 Concrete Cube after 7 and 28 Days

Percentage of FBA (%)	Average Compressive strength (N/mm^2) 7th day	Average Compressive strength (N/mm^2) 28th day
0%	15.43	33.66
5%	17.96	32.06
10%	16.88	32.33
15%	18.87	33.98
20%	16.67	25.07

Table-8, Compressive Strength of FBA 3 Concrete Cube after 7 and 28 Days

Percentage of FBA (%)	Average Compressive strength (N/mm^2) 7th day	Average Compressive strength (N/mm^2) 28th day
0%	16.73	31.81
5%	17.22	32.42
10%	17.89	31.33
15%	18.56	33.13
20%	15.67	29.87

Table-9, Compressive Strength of FBA 4 Concrete Cube after 7 and 28 Days

Percentage of FBA (%)	Average Compressive strength (N/mm^2) 7^{th} day	Average Compressive strength (N/mm^2) 28^{th} day
0%	16.43	32.59
5%	10.96	29.66
10%	12.88	28.31
15%	14.87	26.98
20%	13.67	22.07

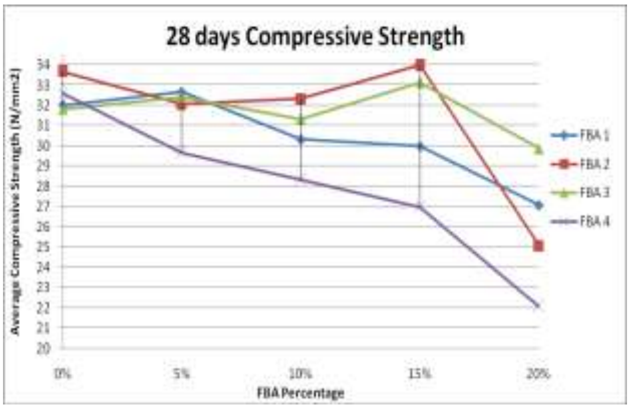

Figure-7, Compare the compressive Strength at 28 days.

Figure-7 shows the variation in 28-day compressive strength with varying dosages of FBA. The optimum percent of ash in each type of FBA could be identified. From the above figure, one can easily see that FBA 2 provides the greatest strength at lower dosages of 10 to 15%. In fact even at 15% cement replacement, the strength is same as that of the reference concrete. Hence, one can conclude that this particular FBA can be used effectively up to 15% to get other benefits of a pozzolanic admixture without sacrificing the strength. Notice that concrete made with FBA 2 has almost the same compressive strength as that of the reference concrete when up to 15% of the cement is replaced. Again, it appears that replacing 15% of the cement is the optimum dosage for FBA 3.

However in the case of FBA 2, the strength drops considerably at 5% dosage and picks up at 10% and 15% dosage. In the case of FBA 4, there was a continuous drop up to 20% dosage. But in FBA 1 the compressive strength picked up from 0% to 5% but at the 15% dosage, the strength was the same as that of the reference mix. To summarize, the four FBAs sampled in this study appear to reach an optimal dosage at between 10-15% of cement replacement.

Although FBA 4 has continuously decreasing compressive strength so from here we can conclude that the FBA 4 could not be used for the pozzolanic concrete but can we used for to accommodate the FBA.

B. *Splitting Tensile Strength*

The splitting tensile strength of the concrete specimens was determined at 7 and 28 days following IS 5816-1999. Cylinders were molded with a diameter of 150 mm and a length of 300 mm. Table -10 to 13 shows the 7 and 28 days splitting tensile strength on concrete of all the specimens. The measured split tensile strength f_{ct} of the specimen shall be calculated to the nearest value 0.05 N/mm^2 using the formula.

$$\frac{2P}{\pi/d} = fct$$

P = Maximum of applied load in N
d = diameter of the specimen

Table -10 Tensile Strength of FBA 1 Concrete Cylinder after 7and 28 Days

Percentage of FBA (%)	Average Tensile strength (N/mm^2) 7^{th} day	Average Tensile strength (N/mm^2) 28^{th} day
0%	2.52	3.60
5%	3.24	3.56
10%	2.61	3.03
15%	2.58	3.16
20%	2.17	2.67

Table -11 Tensile Strength of FBA 2 Concrete Cylinders after 7 and 28 Days

Percentage of FBA (%)	Average Tensile strength (N/mm^2) 7^{th} day	Average Tensile strength (N/mm^2) 28^{th} day
0%	2.56	3.33
5%	2.58	3.37
10%	2.43	3.46
15%	2.62	3.58
20%	2.33	2.8

Table -12 Tensile Strength of FBA 3 Concrete Cylinders after 7 and 28 Days

Percentage of FBA (%)	Average Tensile strength (N/mm^2) 7^{th} day	Average Tensile strength (N/mm^2) 28^{th} day
0%	2.52	3.63
5%	2.97	3.16
10%	3	3.04
15%	2.46	3.08
20%	2.18	2.89

Table -13 Tensile Strength of FBA 4 Concrete Cylinders after 7 and 28 Days

Percentage of FBA (%)	Average Tensile strength (N/mm^2) 7^{th} day	Average Tensile strength (N/mm^2) 28^{th} day
0%	2.52	3.63
5%	2.67	3.61
10%	2.89	3.63
15%	2.54	3.34
20%	2.74	3.49

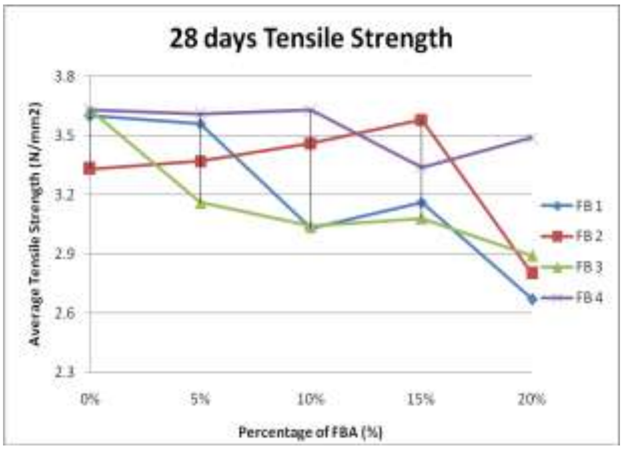

Figure-8, 28 days tensile strength

From the figures-8 it can be easily seen that the tensile strength of concrete with FBA 4 remains more or less constant over a wide range of dosages (i.e., up to 10% cement replacement than 15 to 20% drops slightly), whereas in the case of the other three types of FBA, the strength drops to various levels with an increase in the amount of FBA.

Through comparison of concrete with these different forest based ashes, the rise in strength for concrete containing FBA 2 was the greatest, as reflected in the entire dosing range from 0 to 15%.

Sample FBA 2 contains predominantly CaO as discussed in the previous chapter, which makes the concrete stronger even when high dosages are used due to its hydraulic effect in concrete. Another reason that concrete with FBA 2 has better compressive and tensile strength is that the ash has sufficient fine particles. For the same reason, FBA 1 performs poorly because it has a low CaO content and a very coarse particle-size distribution - the coarsest of all of the FBAs.

There is not that much certainty regarding what are the exact sources of the ashes but they are from various India based sources. Particle size analysis and oxide composition are done on these ashes to know more about them. Adding FBA 3 and FBA 4 decreases the workability of the concrete, whereas adding FBA 1 increased the workability. In the case of concrete containing FBA 2, there was no noticeable change at all in the slump and, consequently, in the workability.

C. Modulus of Rupture

Flexural strength, also known as modulus of rupture a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having a rectangular cross-section is bent until fracture or yielding using a three point flexural test technique. Beam specimens were prepared having a cross section of 150 x 150 x 700 mm to determine the modulus of rupture. The modulus of rupture was also found at the end of 7 and 28 days shown in table-14 to 17 by following IS 516-1959. All specimens have modulus of rupture for 28 days above 2.12MPa.

TABLE -14: Flexural Strength of Concrete Prisms of FBA 1 at 7, 14 and 28 days

Percentage of FBA (%)	Average Flexural strength (N/mm^2) 7th day	Average Flexural strength (N/mm^2) 28th day
0%	2.68	4.20
5%	2.32	4.01
10%	2.46	4.16
15%	2.00	4.35
20 %	1.78	4.01

TABLE -15: Flexural Strength of Concrete Prisms of FBA 2 at 7, 14 and 28 days

Percentage of FBA (%)	Average Flexural strength (N/mm^2) 7th day	Average Flexural strength (N/mm^2) 28th day
0%	2.68	4.20
5%	2.22	3.92
10%	2.36	4.11
15%	2.22	4.18
20 %	1.87	4.01

TABLE -16: Flexural Strength of Concrete Prisms of FBA 3 at 7 and 28 days

Percentage of FBA (%)	Average Flexural strength (N/mm^2) 7th day	Average Flexural strength (N/mm^2) 28th day
0%	3.02	4.20
5%	2.62	3.92
10%	2.66	4.21
15%	2.42	4.44
20 %	1.97	4.01

TABLE -17: Flexural Strength of Concrete Prisms of FBA 4 at 7and 28 days

Percentage of FBA (%)	Average Flexural strength (N/mm^2) 7th day	Average Flexural strength (N/mm^2) 28th day
0%	2.78	4.25
5%	2.22	4.01
10%	2.36	4.11
15%	2.22	3.78
20 %	2.27	3.31

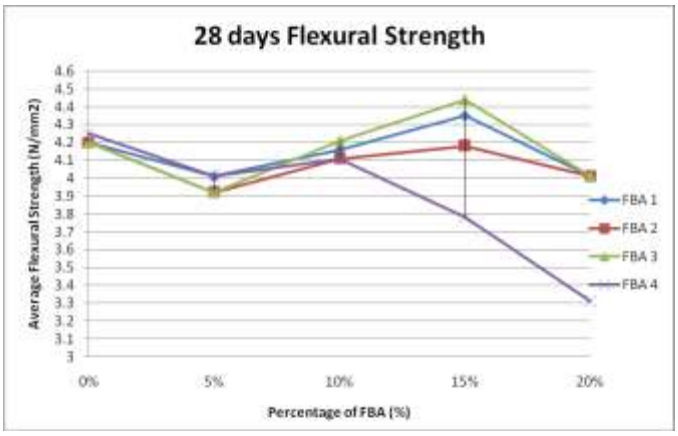

Figure -9 Variation of Flexural Strength with Different Ashes after 28 Days

From the figure-9 it can be easily seen that the flexural strength of concrete with FBA 4 remains more or less constant over a wide range of dosages (i.e., up to 10% cement replacement than 15 to 20% drops eventually), whereas in the case of the other three types of FBA, the strength drops to various levels with an increase in the amount of FBA.

Through comparison of concrete with these different forest based ashes, the rise in strength for concrete containing FBA 3 was the greatest, as reflected in the entire dosing range from 5 to 15%.

There is not that much certainty regarding what are the exact sources of the ashes but they are from various sources. Particle size analysis and oxide composition are done on these ashes to know more about them. Adding FBA 1 and FBA 3 has more or less been the same modulus of rapture, but FBA 4 has noticeable decrease in the modulus of rapture. The results shows that in case of modulus of rapture the FBA1 and FBA 3 has more beneficial in comparison to other waste FBAs.

*D. **Resistance to Sulphate attack of concrete***

This test was conducted on 150 x 150 x 150mm cube specimens. The cubes were casted and cured in water for 28 days. Sodium sulphate ($NaSo_4$) solution of 50g/l is used to evaluate sulphate resistance of concrete. Cubes are immersed in solution after 28 days curing, and 4 cubes were tested for compressive strength at 28 days. Test results are given below in table 5.17. When this compressive strength is compare with the compressive strength of specimen cured in water at same ages also there is increase of FBA1 based concrete with at 5%, 10%, 15%and 20% were also checked. When the replacement of FBA1 with cement in the mix, the strength of specimen tends to decrease as compare to the compressive strength cured in water at same ages. Only upto 10% of FBA1 for 70 days the increase is considerable than the other increase in percentage with different days. Sulphate Resistance of concrete is tested using American Standards is ASTM C1012.According to this code we prepare the concrete cube and tested after placing in sulphate at 56, 70, 90 days, to check the strength variations of concrete after immerection of concrete in Sulphate solution.

The compressive strength was determined from concrete cubes at 28 days. As stated earlier, the values in the case of those specimens subjected to Sulphate Resistance represents a residual strength. In that case only one type of FBA1 is considered.

Table -18 Compressive Strength of FBA Concrete Cubes after 28, 56, 70 and 90 Days.

Percentage of Replacement of FBA (%)	Average Compressive Strength (N/mm^2)			
	at 28 days	at 56 days	at 70 days	at 90 days
0%	34.43	33.63	31.45	27.66
5%	35.54	33.11	30.11	26.13
10%	36.81	32.95	28.56	24.43
15%	35.69	30.97	27.55	23.91
20%	34.89	29.52	25.16	20.11

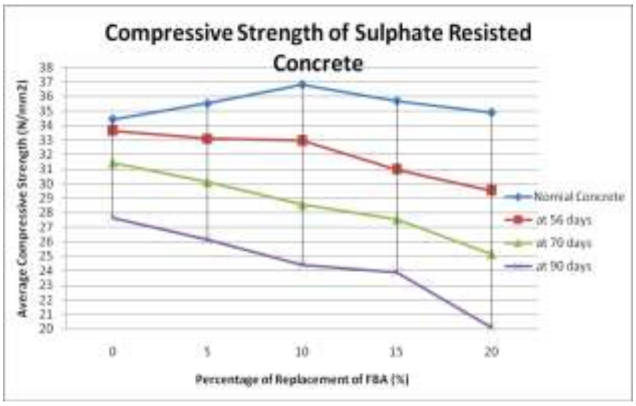

Figure -10, Variation of Compressive Strength under Different days.

Figure-10 shows that concrete made with FBA1 retains its strength up to a cement replacement of 15% at 56 days. For comparison, studies using FBA to reference concrete resistance to sulphate resistance show an optimum performance at 10% cement replacement at 56 days. It was found that strength was optimum initially up to a cement replacement of 10% and strength decreases through increasing percentage from 15 to 20 and gets the initial strength with zero percentage.

V. CONCLUSION

- It was shown in x-ray diffraction charts that in ashes (FBA 1 through 4), the chemicals portlandite, arcanite, quartz and calcite exhibited distinct peaks compared to the other minerals.
- Tests of scanning electron microscope (**SEM**), energy-dispersive x-ray spectroscopy (EDX) and particle-size analysis were done on ashes. Sizes of the particles in FBA 1, FBA 2, FBA 3 and FBA 4 were more than 100 micron is nearly the same as that of Portland cement, ranging between 90 microns. FBA 4 has more of the finer particles, while FBA 1 has the coarsest particle-size distribution.
- With respect to different FBA mineral compositions, it is inferred that in FBA 4, the CaO content is more than the other ashes, which may potentially impart a latent hydraulic effect. Chemical tests on SCBA also show that silica is the most predominant oxide (more than 70%).
- Considering the tensile and compressive strength, FBA 2 was the best suited of the four FBA samples for use as a pozzolana due to its higher CaO and finer particle size, which results in the pozzolanic and filler effect. FBA 1 was the least suited. The four forest-based ash types sampled in this study appear to reach an optimal dosage of ash at between 10 and 15% of cement replacement.

- The effect of FBA on the compressive strength of concrete was examined under Sulphate Resistance. Increasing the percentage of FBA will result in a gradual decrease in the compressive strength of the specimens. However, it was seen that there was only a slight drop in residual strength up to 10% of FBA at 56 days. This drop ranged from 15% to 20%.

- Considering FBAs for the risk of silica alkali reaction and regarding ASTM requirements, FBAs don't obey minimum requirements of ASTM and there would be the risk of alkali silica reaction but regarding findings of other researchers, if the ashes particles become smaller than 75 microns, the potential of alkali silica reaction would be less. SCBA particles are smaller than 75 microns, so the risk for alkali silica reaction would be lower. To avoid risking an alkali silica reaction, it is advised to use smaller ashes and ashes with more CaO.

- Needless to say that, comparing the effect of the forest based ash containing sugar cane bagasse ash in concrete, assuming in the same conditions, sugar cane bagasse ash will bring more acceptable strength while bringing less concerns of sulphate attack and alkali silica reaction. This distinction may be attributed to the following reasons: Sugarcane bagasse ash contains more silica which will result in stronger concrete while forest based contains more CaO which although rendering it latently hydraulic in concrete will likely not result in similar strength like a silica-rich pozzolan. Also, sugarcane bagasse ash contains less Na_2O, K_2O and SO_3 which brings a lower probability of alkali silica reaction and sulphate attack in comparison with forest based ash. Thirdly, sugar cane bagasse ash contains much finer particles in comparison with forest based ashes which will result in higher strength in concrete.

V. RECOMMENDATIONS

- As it was noted, there may be concerns of sulphate attack and alkali silica reaction attack which will lead to expansion, cracks and sooner failure in concrete. In order to overcome these problems, tests of sulphate attack and ASR attack are recommended while usage of finer particle ashes is recommended.
- As the amorphous and crystal phase of the silica in ashes is not that clarified in the test, it's recommended for further tests.
- As we have done Sulphate Resistance test only for the one type of FBA 1, We need to consider all the FBA included concrete and test all the concrete specimens to the loadings.

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