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Properties of concrete incorporating high volumes of class F fly ash and san fibers☆

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Abstract

The results of an experimental investigation to study the effects of replacement of cement (by mass) with three percentages of fly ash and the effects of addition of natural san fibers on the slump, Vebe time, compressive strength, splitting tensile strength, flexural strength and impact strength of fly ash concrete are presented. San fibers belong to the category of "natural bast fibers." It is also known as "sunn hemp." Its scientific (botanical) name is *Crotalaria juncea*. It is mostly grown in the Indian subcontinent, Brazil, eastern and southern Africa and some parts of the United States (Hawaii and Florida). A control mixture of proportions 1:1.4:2.19 with W/Cm of 0.47 and superplasticizer/cementitious ratio of 0.015 was designed. Cement was replaced with three percentages (35%, 45% and 55%) of class F fly ash. Three percentages of san fibers (0.25%, 0.50% and 0.75%) having 25-mm length were used.

The test results indicated that the replacement of cement with fly ash increased the workability (slump and Vebe time), decreased compressive strength, splitting tensile strength and flexural strength and had no significant effect on the impact strength of plain (control) concrete. Addition of san fibers reduced the workability, did not significantly affect the compressive strength, increased the splitting tensile strength and flexural strength and tremendously enhanced the impact strength of fly ash concrete as the percentage of fibers increased.

Keywords: Concrete; San fibers; Fly ash; Mechanical properties

1. Introduction

Cement is the most costly and energy-intensive component of concrete. The unit cost of concrete can be reduced by partial replacement of cement with fly ash. The disposal of fly ash is one of the major issues for environmentalists, as dumping of fly ash as waste material causes severe environmental problems. The utilization of fly ash instead of dumping it as a waste material can be partly used on economic grounds as pozzolana for partial replacement of cement and partly because of its beneficial effects of lower water demand for similar workability, reduced bleeding and lower evolution of heat. It has been used particularly in mass concrete applications and large volume placement to control expansion due to heat of hydration and also helps in reducing cracking at early ages.

The proportion of fly ash used as a cementitious component in concrete depends on several factors. The design strength and workability of concrete, water demand and relative cost of fly ash compared with cement are particularly important in mixture proportioning of concrete. One of the major developments in the area of fly ash utilization in concrete has been the technology of high-performance, high-volume fly ash concrete by Malhotra and Ramezanianpour [1] and Malhotra [2]. High fly ash concretes with fly ash/cementitious ratio up to 75% (by mass) and an aggregate/cement ratio of 6 have compressive and flexural strengths that are more than adequate for lean concrete base or subbase application in pavement structure [3]. Concrete containing 50% replacement by mass of class F fly ash can be designed to have 1- and 28-day cube strengths of 20 and 60 MPa, respectively [4]. High-volume fly ash concrete has adequate early-age and later-age strength developments and considerably lower temperature rise, and its applications should have a water content of not less than 115 kg/m^3 and a

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Table 1
Chemical composition of fly ash

Chemical analysis	Class F fly ash (%)
SiO_2	57.3
Al_2O_3	27.1
Fe_2O_3	5.4
$SiO_2+Al_2O_3+Fe_2O_3$	89.8
CaO	6.1
MgO	2.0
TiO_2	1.3
K_2O	0.6
Na_2O	0.4
SO_3	1.4
LOI (1000 °C)	0.8
Moisture	0.5

sufficient amount of a retarded version of superplasticizer to maintain satisfactory slump and placing characteristics [5]. The effects of high temperatures and high pressures on the strength and elasticity of concrete containing various levels of high-calcium lignite fly ash and a fixed percentage of silica fume are reported in the literature [6] and authors have concluded that gradual deterioration of strength and static modulus of elasticity was observed with a rise in temperature. The effects of fly ash type and content on the permeability characteristics of mortar materials subjected to two different curing conditions and two ages are presented [7] and authors have concluded that as moist curing duration increased, the fly ash mortar became less permeable. The interruption of moist curing and exposure to a low-humidity (interior) environment led to increased permeability, except for the class F fly ashes after longer moist curing duration, for which permeability stayed almost constant.

The use of fly ash in concrete is found to affect strength characteristics adversely. A loss in strength of concrete can be retrieved to a large extent by incorporating fibers, which have proved their worth in enhancing the strength characteristics of concrete. In this paper, an effort has been made to study the effects of natural san fibers on the properties of fly ash concrete.

San is a natural bast fiber. It is also known as ‘‘sunn hemp.’’ Its scientific (botanical) name is *Crotalaria juncea*. It is mostly grown in the Indian subcontinent, Brazil, eastern and southern Africa and some parts of the United States (Hawaii and Florida). San (sunn hemp) plant is about 1–2.5 m in length and light green in color. The diameter of the plant varies from 10 to 30 mm. The stem of the plant is fully covered with thin layer of fibrous skin, which once extracted from the stem is used as fibers. San fibers are used in making twines, rug yarns, tissue papers, canvas and cordage. Siddique [8,12] has reported its physical and mechanical properties such as length, diameter, tensile strength, modulus of elasticity, tensile strength in alkaline environment and dimensional stability in wet and dry conditions. The effects of natural san fibers on the properties of concrete and of fly ash concrete have been extensively reported by Siddique [8,10–14,16], Siddique and Venkataramana [9] and Siddique and Singh [15].

This paper presents the effects of san fibers on the slump, Vebe time, compressive strength, splitting tensile strength, flexural strength and impact strength of fly ash concrete.

2. Experimental procedure

2.1. Materials

2.1.1. Cement

Ordinary Portland (43 grade) cement was used. It was tested per Indian Standard Specifications IS: 8112-1989 [17] and met all the requirements.

2.1.2. Fly ash

Class F fly ash obtained from thermal power plant at Bathinda, India was used in this investigation. Chemical composition of the fly ash was determined per ASTM C 311 and the results are given in Table 1.

2.1.3. Fine aggregate

Natural sand with a 4.75-mm maximum size was used as fine aggregate. It was tested per Indian Standard Specifications IS: 383-1970 [18]. Its physical properties and sieve analysis results are given in Tables 2 and 3, respectively.

2.1.4. Coarse aggregate

Coarse aggregate used in this study was 12.5-mm nominal size. It was tested per Indian Standard Specifications IS: 383-1970 [18]. Its physical properties and sieve analysis results are given in Tables 2 and 3, respectively.

2.1.5. Fibers

San is natural bast fiber. Natural San fibers are extracted from the stem of the plant known as san (also commonly known as sunn hemp). It is mostly grown in the Indian subcontinent, Brazil, eastern and southern Africa and some parts of the United States (Hawaii and Florida). In this investigation, san fibers having a length of 25 mm and three percentages by volume of concrete (0.25%, 0.50% and 0.75%) were used. The physical and mechanical properties of san fibers are given in Table 4.

Table 2
Physical properties of aggregates

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.63	2.62
Fineness modulus	2.30	6.62
SSD absorption (%)	0.88	1.13
Void (%)	34.2	38.2
Density (kg/m^3)	1685	1635

Table 3
Sieve analysis of aggregates

Fine aggregates		Coarse aggregates	
Sieve no.	Percent passing	Sieve size (mm)	Percent passing
4.75 mm	98.2	12.5	96
2.36 mm	94.6	10	75
1.18 mm	79.2	4.75	9
600 μm	61.2		
300 μm	36.8		
150 μm	6.2		

2.1.6. Superplasticizer

A commercially available superplasticizer Centriplast FF90 based on melamine formaldehyde was used in all mixtures.

2.2. Mixture proportions

First, a control mixture (with out fly ash) was designed in accordance with the provisions of Indian Standard Specifications IS: 10262-1982 [19] to have a 28-day cube compressive strength of 36 MPa. Then, cement was replaced with three fly ash percentages (35%, 45% and 55%) by mass. After this, three percentages (0.25%, 0.50% and 0.75%) of san fibers were added in each of the fly ash concrete mixtures containing 35%, 45% and 55% fly ash. The W/Cm ratio was maintained at 0.47 ± 0.02 and air content was kept at $4.8 \pm 0.2\%$. Superplasticizer/cementitious materials ratio was kept around 0.015. Concrete mixtures were made in power-driven revolving-type drum mixers of 0.76 m^3 capacity.

2.3. Preparation, casting and testing of specimens

Initially, cement and fly ash were dry mixed properly. After all the constituent materials were mixed, about 1/5 of the required water was added to the mixture. Small quantities of fibers were released manually and gradually taking care that the fibers were not mixed in bundles. After adding about 1/3 of the quantity of fibers, more water (about 1/3 of the remaining quantity) was added to the mixer and the remaining quantity of fibers was added again slowly and in small quantities. Finally, the remaining water was added and the mixing was done until good homogeneous mixture, as visually observed, was obtained. If any lumping or balling was found at any stage, it was taken out, loosened and again added manually.

Table 4
Physical and mechanical properties of san fibers

Property	Value
Diameter (mm)	0.03–0.10
Tensile strength (MPa)	195–235
Elongation (%)	1.19–1.36
Water absorption (%)	85–120
Density (kg/m^3)	1010–1040

Table 5
Test results of plain and fly ash concrete

Mixture type	Slump (mm)	Vebe time (s)	Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)
PC	45	31	36.0	4.0	5.3
FC35	60	22	26.7	2.9	2.9
FC45	65	19	24.6	2.6	2.5
FC55	75	15	23.1	2.2	2.3

Following the mixing, slump and Vebe time tests were performed for plain (control) concrete, fly ash concrete and fiber-reinforced fly ash concretes. Standard 150-mm cube specimens for compressive strength, cylinders of 153×305 mm for splitting tensile strength and beams of $101.6 \times 101.6 \times 508$ mm for flexural strength were cast in accordance with the provisions of Indian Standard Specifications IS: 516-1959 [20]. For impact strength, concrete sheets of size $500 \times 500 \times 30$ mm were cast. The specimens were covered immediately for complete moisture retention. The specimens were demoulded after 24 h of casting and were then placed in a water curing tank at a temperature of 26 ± 1 °C. The specimens were tested after 28 days of curing. The plain (control) concrete specimens were designated as "PC." Fly ash concrete specimens were designated as "FC35," FC45 and FC55. "FC35" means concrete specimens containing 35% fly ash. Results of slump test, Vebe time test, compressive strength, splitting tensile strength and flexural strength of plain and fly ash concrete are given in Table 5.

Compressive strength, splitting tensile strength, and flexural strength were determined at 28 days as per the provisions of Indian Standard Specifications IS 516-1959 [20]. For impact strength measurement, a set-up was designed. Impact strength test was carried out by a falling weight method. In this test, a cylindrical metallic piece of weight 40 N was dropped from a constant height (1000 mm). The number of blows required to fail the specimens gives the impact strength of the slabs. Because damage inflicted by the blows of impact load stays during the subsequent blows, it was assumed that the slabs absorb impact energy imparted by the drop of load. The cumulative energy imparted to the slab in kN m to cause failure is expressed as mgh multiplied by average number of blows.

3. Results and discussion

3.1. Workability

The results of the effect of replacement of cement with three percentages of fly ash on slump and Vebe time are given in Table 5. It is evident from the table that with an increase in the percentage of fly ash content, workability (slump and Vebe time) increased. This increase in workability of concrete is due to the "ball bearing" action of the spherical particles of fly ash. The effect of san fibers on the slump and Vebe time of fly ash concrete are shown in Figs. 1 and 2. The slump was found to decrease with an increase in the percentage of san fibers for all the three percentages of fly ash. For 35% fly ash concrete, the slump loss of 15 mm was observed with an increase in the percentage of fibers, and there was slump loss of 20 and 25 mm for 45% and 55% fly ash concrete, respectively. Similarly, the san fibers have their adverse affect on the Vebe time of fly ash concrete. Vebe time of fly ash concrete increased with an increase in fly ash percentage. For 35% fly ash concrete, there was an increase of Vebe time of 32 s with an increase in percentage of fibers, and it was 26 and 24 s for 45% and 55% fly ash concrete, respectively.

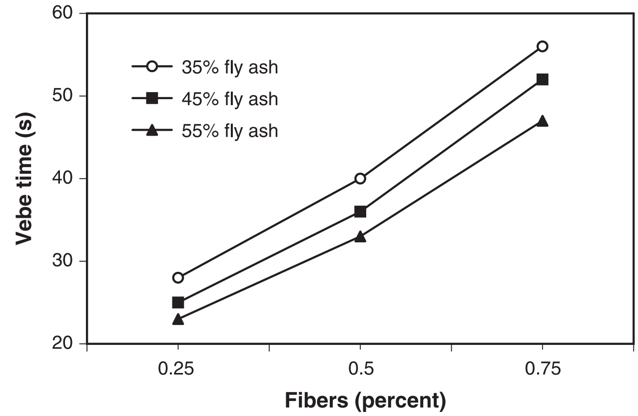

Fig. 2. Effect of san fibers on the Vebe time of fly ash concrete.

3.2. Compressive strength

The effect of replacement of cement with three percentages of fly ash on the compressive strength of concrete is given in Table 5. It is clear from Table 5 that the replacement of cement with 35%, 45% and 55% of fly ash reduced the compressive strength of concrete at 28 days by 32%, 43% and 48%, respectively. The results of addition of san fibers on the compressive strength of fly ash concrete are shown in Fig. 3. It is clear from the Fig. 3 that for a particular percentage of fly ash, there was a decrease in the compressive strength of fly ash concrete, as the percentage of fibers increased from 0.25% to 0.75%. However, this reduction in strength with the addition of fibers continued to decrease with an increase in percentage of fly ash content from 35% to 55%. Reduction in compressive strength was between 8% and 13% for 35% fly ash content, between 4% and 8% for 45% fly ash content and between 2% and 9% for 55% fly ash content. Generally, presence of fibers induces porosity and reduces the compressive strength. However, in this case, addition of fibers reduced the compressive strength between 2% and 13% depending on the fly ash content, which was not significant decrease, considering contributions of fibers in enhancing tensile and impact strengths. This decrease in compressive strength may also be due to the fact that san fibers have been found to be dimensionally stable [8–14].

3.3. Splitting tensile strength

The test results of the replacement of cement with three percentages of fly ash on the splitting tensile strength of concrete are given in Table 5. It is clear from Table 5 that the replacement of cement with 35%, 45% and 55% of fly ash reduced the splitting tensile strength of concrete by 23%, 36% and 49%, respectively. The results of addition of san fibers on the splitting tensile strength of fly ash concrete are shown in Fig. 4. Fig. 4 shows that for a particular percentage of fly ash, there was an increase in the splitting tensile strength of fly ash concrete, as the percentage of fibers was increased from 0.25% to 0.75%. Increase in the splitting tensile strength was between 11% and 27% for 35% fly ash content, between 9% and 24% for 45% fly ash content and between 8% and 22% for 55% fly ash content.

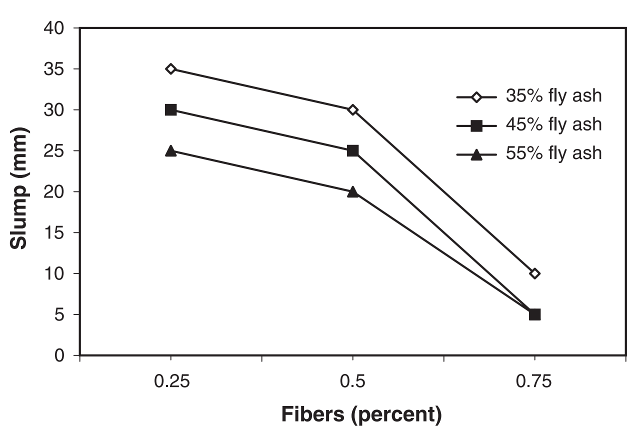

Fig. 1. Effect of san fibers on the slump of fly ash concrete.

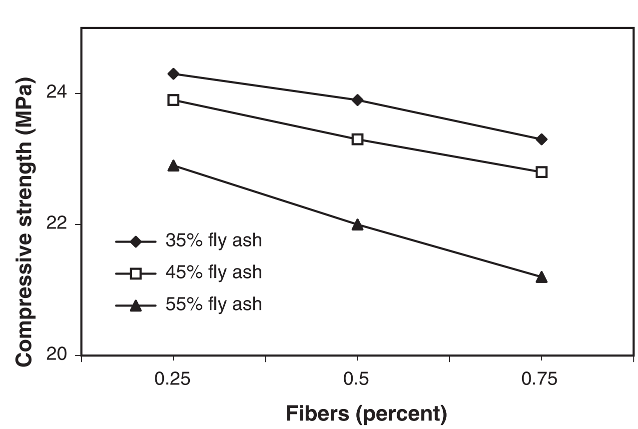

Fig. 3. Effect of san fibers on the compressive strength of fly ash concrete.

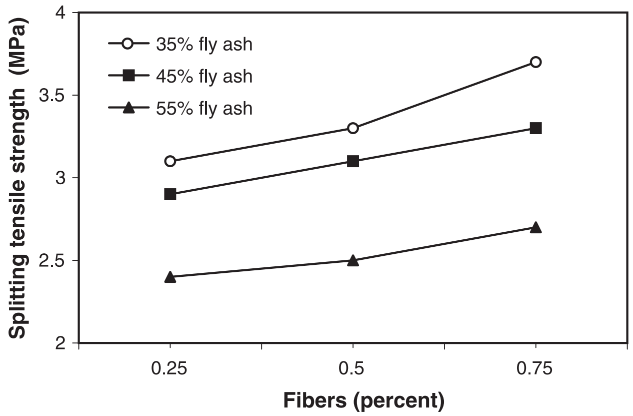

Fig. 4. Effect of san fibers on the splitting tensile strength of fly ash concrete.

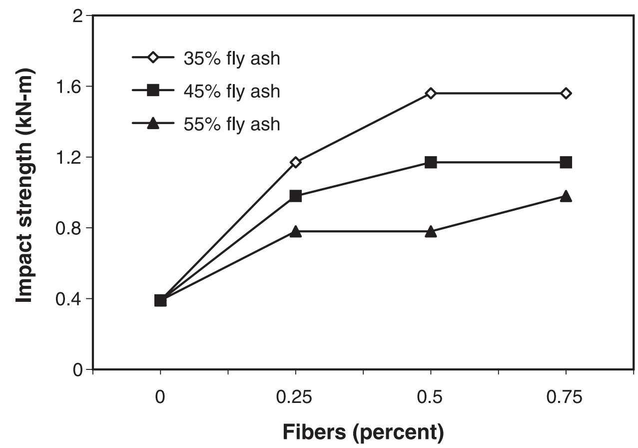

Fig. 6. Effect of san fibers on the impact strength of fly ash concrete.

3.4. Flexural strength

The effect of replacement of cement with three percentages of fly ash on the flexural strength of concrete is shown in Table 5. It is clear from Table 5 that replacement of cement with 35%, 45% and 55% of fly ash reduced the flexural strength of concrete by 39%, 48% and 56%, respectively. The results of addition of san fibers on the flexural strength of fly ash concrete are shown in Fig. 5. Fig. 5 shows that for a particular percentage of fly ash content, there was an increase in the flexural strength of fly ash concrete, as the percentage of fibers was increased from 0.25% to 0.75%. Increase in the flexural strength was between 5.2% and 12.4% for 35% fly ash content, between 5% and 10.8% for 45% fly ash content and between 4% and 9% for 55% fly ash content.

3.5. Impact strength

The test results of impact strength of san fiber-reinforced fly ash concrete at ultimate failure are shown in Fig. 6. From this figure, it is clear that for all the three fly ash percentages, addition of san fibers enhanced the impact strength with an increase in percentage of fibers. With 35% fly ash content, the improvement in strength was 2–3 times with the increase in percentage of fibers, whereas it was 1.5–2.0 and 1–1.5 times with 45% and 55% fly ash content, respectively.

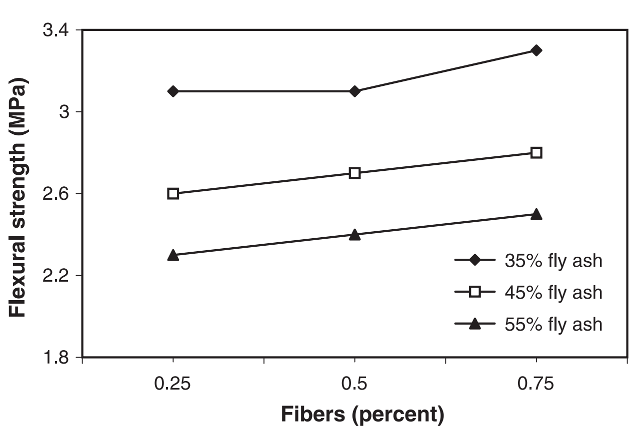

Fig. 5. Effect of san fibers on the flexural strength of fly ash concrete.

4. Conclusions

The following conclusions are drawn from the present study:

1. The replacement of cement (by mass) with three percentages of fly ash (35%, 45% and 55%) increased the workability (both slump and Vebe time) of concrete with an increase in fly ash percentages. This is due to the "ball bearing" action of the spherical particles of fly ash. The slump of fly ash concrete was found to decrease with an increase in the percentage of san fibers for all the three percentages of fly ash. San fibers had adverse affect on the Vebe time of fly ash concrete. Vebe time of fly ash concrete increased with an increase in the fly ash percentages.
2. The replacement of cement with three percentages of fly ash content reduced the compressive strength of concrete by 32%, 43% and 48%, respectively. However, addition of san fibers did not have significant effect on the compressive strength of fly ash concrete.
3. The splitting tensile strength of concrete decreased by 23%, 36% and 49% with the replacement of cement with 35%, 45% and 55% of fly ash. Addition of san fibers increased the splitting tensile strength of fly ash concrete, as the percentage of fibers was increased from 0.25% to 0.75%.
4. Replacement of cement with the three percentages of fly ash reduced the flexural strength by 39%, 48% and 56%, respectively. However, addition of san fibers marginally increased the flexural strength of fly ash concrete, as the percentage of fibers was increased from 0.25% to 0.75%.

5. For all three fly ash contents, addition of san fibers significantly enhanced the impact strength with the increase in percentage of fibers. With 35% fly ash content, the improvement in strength was 2–3 times with the increase in percentage of fibers, whereas it was 1.5–2.0 and 1–1.5 times with 45% and 55% fly ash content, respectively.

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