Leonardo Electronic Journal of Practices and Technologies
ISSN 1583-1078
Issue 12, January-June 2008
p. 25-36

Fracture Toughness and Impact Strength of High-Volume Class-F Fly Ash Concrete Reinforced with Natural San Fibres

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Abstract

Results of experimental investigation carried out to study the effects of addition of natural san fibres on the fracture toughness and impact strength of high-volume fly ash concrete are presented in this paper. San fibres belong to the category of 'Natural Bast Fibres', also known as 'Sunn Hemp'. Its scientific (botanical) name is Crotalaria Juncea. It is mostly grown in the Indian Sub-Continent, Brazil, Eastern and Southern Africa, and in some parts of the U.S.A. Initially, a control mixture without fly ash was designed. Then, cement was replaced with three percentages (30, 40 and 50%) of low-calcium (Class F) fly ash. Three percentages of san fibres (0.30, 0.60 and 0.90%), having 25 mm length, were used. Tests were performed for compressive strength, fracture toughness, and impact strength at the ages of 28 and 91 days.

The test results indicated that the replacement of cement with fly ash decreased the compressive strength and fracture toughness, and had no significant effect on the impact strength of plain (control) concrete. Addition of san fibres did not affect significantly the compressive strength, increased the fracture toughness and impact strength of high-volume fly ash concrete as the percentage of fibres increased.

Keywords
Compressive strength; Concrete; Fracture Toughness; Fly Ash; Impact Strength; San Fibres.

Introduction

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 his associates [1, 2]. High-volume fly ash concrete has emerged as a construction material in its own right. These concretes generally contain more than 40% fly ash by mass of total cementitious materials. Many researchers have reported their findings on the various aspects of high-volume fly ash concrete [1-14]. The use of fly ash in concrete is found to affect strength characteristics adversely. A loss in strength of concrete can be retrieved largely by incorporating fibres, which have proved their worth in enhancing the strength characteristics of concrete.

Not much research has been reported on the effects of natural fibres on the properties of mortar/concrete/fly ash concrete. Uzomaka [15] reported physical characteristics of natural fibre “akwara”, and akwara reinforced concrete. Lewis and Mirihagalia [16] conducted tests on mortar reinforced with natural fibres such as water reed, elephant grass, plantain, and musamba. Based on the test results they concluded that among the four types of natural fibres, elephant grass showed the greatest promise as a reinforcing material. Castro and Naaman [17] used natural fibres Lechuguilla and Maguey of the Agave family as reinforcement in cement mortar, and concluded that fibres did not have significant differences in either mechanical properties or the reinforcing efficiency of Maguey or Lechuguilla fibres. Mawenya [18] reported that sisal fibres had significant mechanical properties that make them eligible as reinforcement for concrete. Fageiri [19] reported that the tensile properties of Kenaf fibres were comparable to those of some natural fibres (sisal) and synthetics fibres (polypropylene) that are used to reinforce a low tensile strength matrix, and addition of kenaf fibres enhanced the bending and impact resistance of sheets. Mwamila [20] has proposed the idea of reinforcing concrete beams with the twines made of sisal fibres.

Siddique [21-28] extensively reported the effects of natural san fibres on the properties of concrete and fly ash concretes. Siddique[21] reported the physical and mechanical properties of san fibres such as length, diameter, tensile strength, modulus of elasticity, tensile strength in alkaline environment, and dimensional stability in wet and dry conditions. Siddique and Venkataramana [22] reported that presence of san fibre enhanced the static and impact strength of concrete sheets significantly. Siddique [23] reported the effect of addition of various percentages and lengths of natural san fibres on the compressive stress-strain characteristics of concrete. He concluded that ductility of concrete increased with the increase in percentage of fibres, and modulus of elasticity of san fibre reinforced concrete does not significantly differ from that of plain concrete. Siddique [24] concluded that san fibre did not significantly affect the compressive strength of concrete up to 0.75% of fibre content by volume of concrete, but beyond this fibre content, strength decreased sharply. Siddique [25] reported physical and mechanical properties of san fibre, and has also be compared the experimental results of compressive strength, split tensile strength and flexural strength with the model based on law of mixture. Siddique [26] reported that the twines made of san fibres enhanced the load carrying capacity and ductility of concrete beams, and could be effectively used as reinforcement in concrete beams. Siddique [27] concluded that san fibres did marginally improved the flexural behaviour of the reinforced concrete beams. In a recently published paper, Siddique [28] has reported the effects of san fibres on the properties of high-volume fly ash concrete at the age of 28 days.

Experimental Program

Materials

Ordinary Portland cement conforming to the requirements of Indian Standard Specifications IS: 8112-1989 [29] was used. Class F fly ash was obtained from thermal power plant. Chemical composition of the fly ash met ASTM C 618 requirements, and the results are given in Table 1. Natural sand with a 4.75 mm maximum size was used as fine aggregate and natural gravel with 12.5 mm maximum size was used as coarse aggregate. Both these aggregates were obtained locally and met requirements of IS: 383-1970 [30]. The sand used had a density of 2610 kg/m^3 and fineness modulus of 2.65. The coarse aggregate used had a density of 2620 kg/m^3 and fineness modulus of 6.86.

Table 1. Chemical composition of fly ash

Chemical Analysis	Class F Fly Ash (%)	Requirement ASTM C 618 (%)
Silicon Dioxide, SiO_2	54.4	--
Aluminum Oxide, Al_2O_3	24.80	--
Ferric Oxide, Fe_2O_3	5.2	--
SiO_2 + Al_2O_3 + Fe_2O_3	84.0	70.0 min.
Calcium Oxide, CaO	5.1	--
Magnesium Oxide, MgO	2.5	5.0 max.
Titanium Dioxide, TiO_2	1.4	--
Potassium Oxide, K_2O	0.8	--
Sodium Oxide, Na_2O	0.6	1.5 max.
Sulfur trioxide, SO_3	1.6	5.0 max.
LOI (1000^{o}C)	2.3	6.0 max.
Moisture	0.5	3.0 max.

San is a natural bast fibre. It is also known as “Sunn Hemp”. Its scientific (botanical) name is Crotalaria Juncea. The san plant is about 1 to 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 a thin layer of fibrous skin, which once extracted from the stem, is used as fibre. In this investigation, san fibres having a length of 25 mm were used at three percentages (0.30, 0.60 and 0.90%) by volume of concrete. The physical and mechanical properties of san fibres are given in Table 2. A commercially available superplasticizer Centriplast FF90, based on melamine formaldehyde was used in all mixtures.

Table 2. Properties of san fibres

Property	Value
Diameter, mm	0.03 to 0.10
Tensile Strength, MPa	195 to 235
Elongation, %	1.19 to 1.36
Water absorption, %	85 to 120
Density, kg/m^3	1010 to 1040

Mixture Proportions

A control mixture (without fly ash) having proportions of 1:1.5:2.3 with W/Cm of 0.47 and superplasticizer-cementitious ratio of 0.015 was designed per Indian Standard Specifications IS: 10262-1982 [31]. Cement was replaced at three percentages (30, 40 and 50%) with class-F fly ash. Three percentages of san fibres (0.25, 0.50 and 0.75%), having 25 mm length, were used. After this, three percentages (0.30, 0.60, and 0.90%) of san fibres by volume of concrete were added in each of the fly ash concrete mixtures.

Casting and Testing of Specimens

Standard 150 mm cubes for compressive strength and 101.6 × 101.6 × 508 mm beams for fracture toughness were cast per the provisions of Indian Standard Specifications IS: 516-1959 [32]. For impact strength, concrete sheets of size 500 × 500 × 30 mm were cast. The specimens were covered immediately for complete moisture retention. The specimens were tested at the ages of 28 and 91 days. Compressive strength and fracture toughness were determined per Indian Standard Specifications IS 516-1959 [32]. 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 40 N weight was dropped from a constant height (1000 mm). The number of blows required to fail the specimens gives the impact strength of the slabs. Since damage inflicted by the blows of impact load stayed during the subsequent blows, it was assumed that the slabs absorbed 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 x average number of blows.

Results and Discussion

Compressive Strength

Compressive strength test results of concrete mixtures containing 30, 40, and 50% fly ash, and the effects of san fibres on the compressive strength of high-volume fly ash concrete are shown in Figure 1. At the age of 28 days, concrete mixtures containing 30, 40, and 50% fly ash achieved compressive strengths of 27, 25 and 23 MPa, respectively. Compressive strength of concrete mixtures increased at 91 days. Concrete mixtures containing 30%, 40%, and 50% fly ash achieved strength of 34, 30, and 28 MPa at the age of 91 days. The increase in compressive strengths of fly ash concrete mixtures was probably due to significant pozzolonic reaction of fly ash.

It is evident from Figure 1 that for a particular fly ash percentage, compressive strength of high-volume fly ash concrete mixtures decreased with the increase in fibre percentage at 28 and 91 days. However, the reduction in compressive strength with the addition of fibres continued to decrease with an increase in percentage of fly ash content from 30 to 50%.

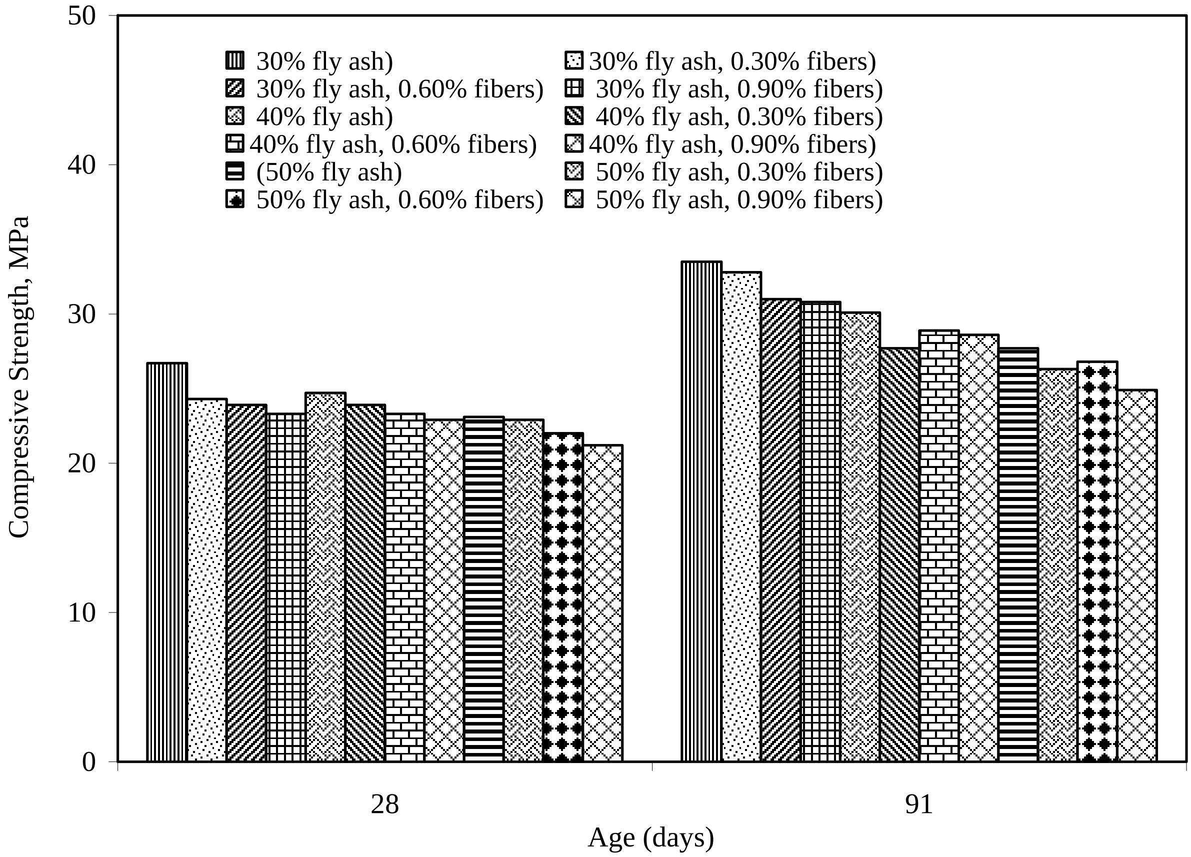

Figure 1. Compressive Strength versus Age

At the age of 28 days, the reduction in compressive strength was between 8 and 12% for the mixture containing 30% fly ash, between 3 and 7% for the mixture containing 40% fly ash, and between 2 and 8% for the mixture containing 50% fly ash. At the age of 91 days, the reduction in compressive strength was between 2 and 7% for the mixture with 30% fly ash, between 4 and 8% for the mixture with 40% fly ash, and between 3 and 9% for the mixture with 50% fly ash.

Fracture Toughness

Fracture toughness of concrete mixtures containing 30, 40, and 50% fly ash, and the effects of addition of san fibres on the fracture toughness of high-volume fly ash concrete are shown in Figure 2.

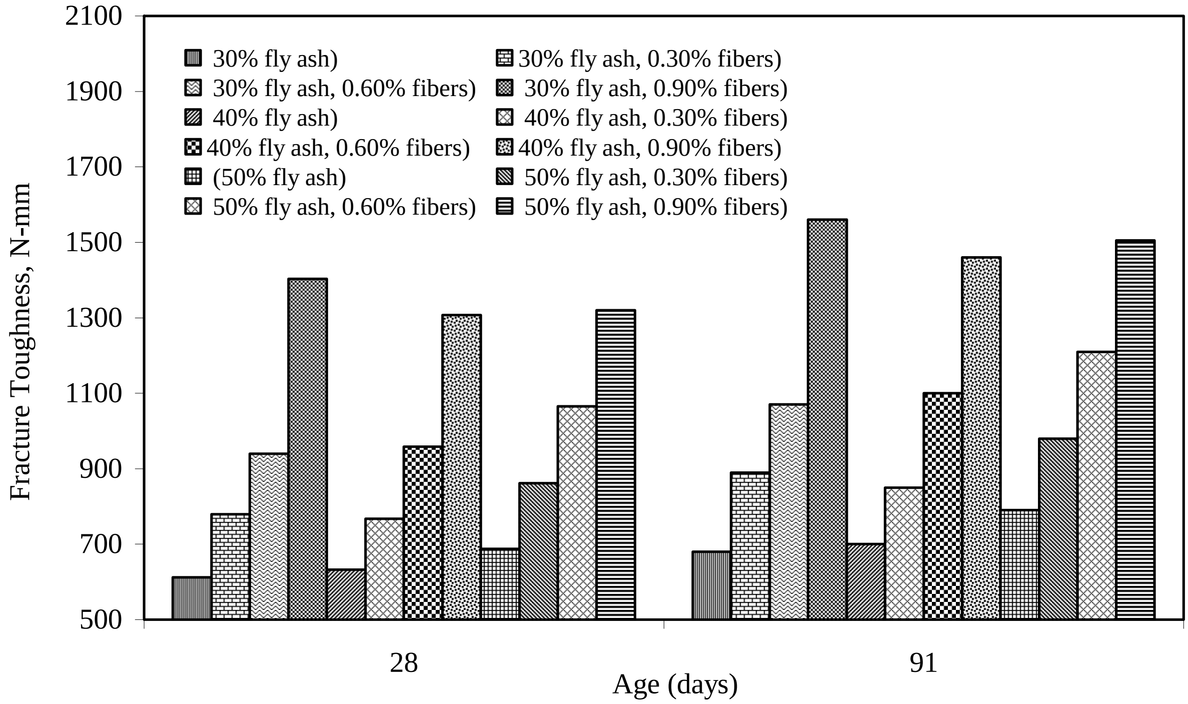

Figure 2. Fracture toughness Versus Age

At the age of 28 days, mixtures containing 30, 40, and 50% fly ash achieved fracture toughness values of 612, 632, and 688 N-mm, respectively. At the age of 91 days, the mixture made with 30% fly ash achieved a toughness of 680 N-mm, whereas the mixtures made with 40 and 50% fly ash achieved toughness values of 700 and 790 N-mm, respectively.

It is clear from Figure 2 that for a particular fly ash percentage, fracture toughness of the fly ash concrete mixtures increased with increase in fibre percentages at the ages of 28 and 91 days. At 28 days, toughness values were between 780 and 1404 N-mm for the mixture made with 30% fly ash, between 770 and 1280 N-mm for the mixture made with 40% fly ash, and between 860 and 1320 N-mm for the mixture made with 55% fly ash. At 91 days, fracture toughness further increased. At 91 days, fracture toughness values were between 890 and 1560 N-mm for the mixture containing 30% fly ash, between 850 and 1460 N-mm for the mixture containing 40% fly ash, and between 980 and 1505 N-mm for the mixture containing 50% fly ash.

Impact Strength

Results of impact strength are shown in Figure 3.

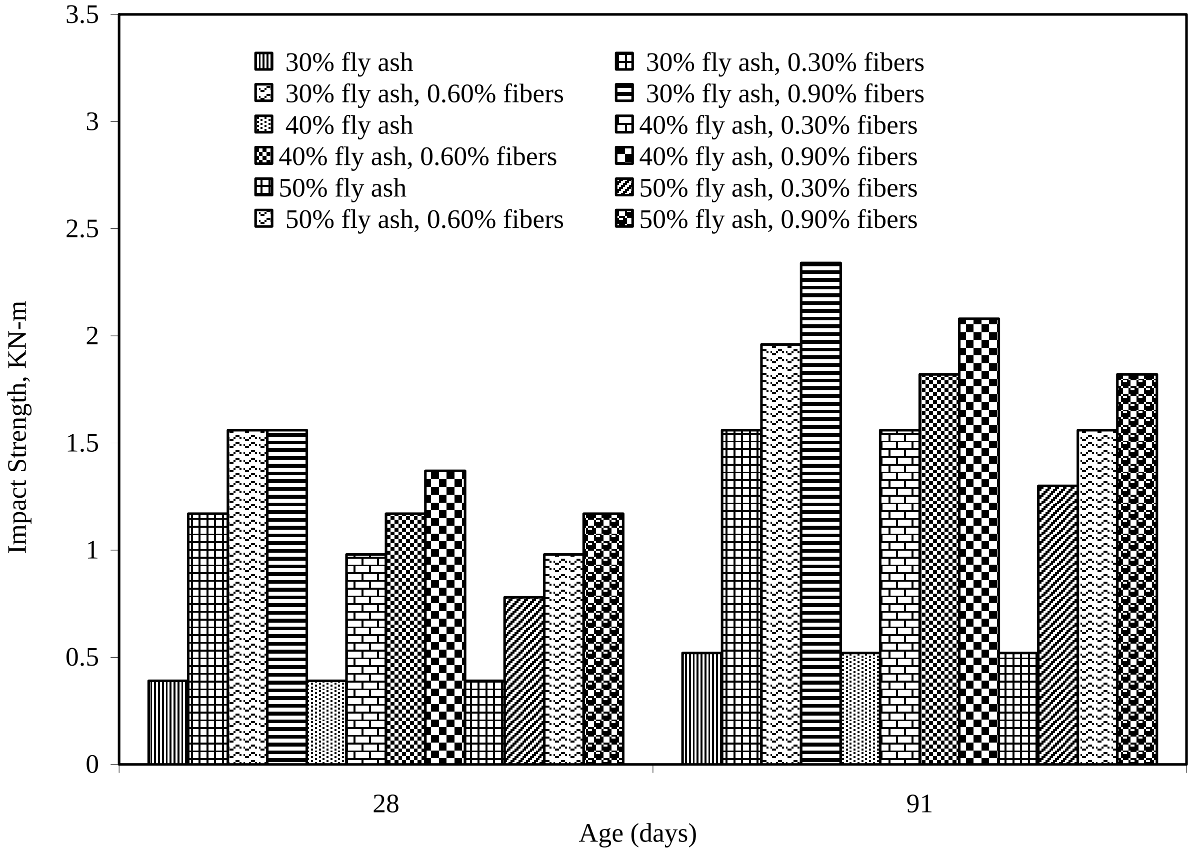

Figure 3. Impact Strength versus Age

It is clear from the figure 3 that for all fly ash concrete mixtures, addition of san fibres enhanced the impact strength significantly with an increase in percentage of fibres. For concrete mixtures containing 30% fly ash, improvement in impact strength was between 2 and 3 times at the age of 28 days, whereas it was between 2 and 3.5 times at 91 days. For concrete with 40% fly ash, improvement in impact strength was between 1.5 to 2.5 times at the age of 28 days, whereas it was between 2 and 3 times at 91 days. For concrete mixtures with 50%

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fly ash, improvement in impact strength was between 1 and 2 times at the age of 28 days, with the increase in percentage of fibres, whereas it was between 1.5 and 2.5 times at 91 days.

Conclusions

The following conclusions are drawn from the present investigation:

1. Compressive strength and fracture toughness of high-volume fly ash (HVFA) concrete increased with age in comparison with 28-day strength. Increase in the strengths of HVFA concrete clearly indicated the pozzolanic reaction of fly ash.
2. San fibres did not significantly affect the compressive strength of high-volume fly ash concrete. At the age of 28 days, reduction in compressive strength was between 2 and 12% depending up on the fly ash content and fibre percentage. At 91 days, compressive strength of san fibre reinforced high-volume fly ash concrete increased, which is clearly due to the pozzolanic reaction of fly ash.
3. Addition of san fibres marginally increased the 28-days fracture toughness of high-volume fly ash concrete depending upon the fly ash content and fly ash percentage. Fracture toughness of high-volume fly ash concrete also increased with age.
4. The use of san fibres significantly enhanced the 28-day impact strength (1 and 3 times) of high-volume fly ash concrete with the increase in percentage of fibres. With the increase in age, improvement in impact strength was of the order of 1.5 to 3.5 times at the age of 91 days.

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