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Toughness study on fly ash based fiber reinforced concrete

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Abstract

The objective of the present investigation is to study the toughness of steel fiber-reinforced fly ash concrete based on the Japan Society of Civil Engineers (JSCE) approach. Fly ash is also considered as a hazardous waste due to the probable leaching of potentially toxic substances into the surface water, ground water, and soil. The ash content of the Indian coal (30% to 50%) contributes to these large volumes of fly ash. This paper highlights about the behavior of concrete when fly ash and steel fiber are added in concrete. Fiber-reinforced concrete is a concrete containing fibrous material which increases its structural integrity. The addition of random fibers to concrete considerably improves its structural characteristics such as static flexural strength, impact strength, tensile strength, ductility, and flexural toughness (Qian and Stroeven, Cem. Concr. Res. 30:63–68, 2000). Fly ash has been used by replacing cement in percentages, and steel fibers are added by volume of concrete in different percentages. Grooved type of steel fibers of aspect ratio 50 was used in this study. Flexural strength test was carried out for the specimens, and its results were highlighted. The toughness factor as measured by the JSCE approach is reported, and there is a good correlation between the steel fibers added in various percentages such as 1.5%, 2%, and 2.5% and the calculated toughness factor.

Keywords: Fly ash; Steel fiber; Flexural strength; Toughness factor

Introduction

Fly ash is a residual material of energy production using coal, which has been found to have numerous advantages for its use in the concrete industry. Some of the advantages include improved workability, reduced permeability, increased ultimate strength, reduced bleeding, and reduced heat of hydration Qian and Stroeven (2000). The use of fly ash in concrete is found to affect strength characteristics adversely. One of the ways to compensate for the early-age strength loss associated with the usage of fly ash is by incorporating fibers, which have been proved very efficient in enhancing the strength characteristics of concrete (Stroeven and Babut 1986).

For long-term strength and toughness and high stress resistance, steel fiber-reinforced concrete (SFRC) is increasingly being used in structures such as flooring, housing, precast tunneling, heavy duty pavement, and mining (Yao et al. 2003). The addition of steel fibers significantly improves many of the engineering properties of mortar and concrete, notably impact strength and toughness. The enhanced performance of fiber-reinforced concrete compared to its unreinforced counterpart comes from its improved capacity to absorb energy during fracture. While a plain unreinforced matrix fails in a brittle manner at the occurrence of cracking stresses, the ductile fibers in fiber-reinforced concrete continue to carry stresses well beyond matrix cracking, which helps maintain structural integrity and cohesiveness in the material (Bentur and Mindess 1990).

Poor toughness, a serious shortcoming of high strength concrete, can be overcome by reinforcing with short discontinuous fibers. Fibers primarily control the propagation of cracks and limit the crack width. Further, if properly designed, fibers undergo a pullout process, and the frictional work needed for pullout leads to a significantly improved energy absorption capability. This energy absorption attribute of SFRC is often termed as toughness (Pierre et al. 1999). The importance of fiber geometry and matrix strength on the toughness characteristics of SFRC has been clearly established by earlier researchers (Soroushian et al. 1992).

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Table 1 Mix proportions

Mix	Water (l)	Cement (kg)	Fly ash (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Fiber content (kg)			
						0%	1.5%	2%	2.5%
0% fly ash	180.00	405.48	-	669.59	1,088.35	-	0.216	0.288	0.361
20% fly ash	198.78	324.38	81.09	663.60	1,078.60	-	0.216	0.288	0.361
40% fly ash	202.74	243.28	162.19	656.60	1,067.23	-	0.216	0.288	0.361
60% fly ash	202.74	162.19	243.28	650.60	1,057.48	-	0.216	0.288	0.361

The most common method to measure toughness is to use the load-deflection curve obtained using a simply supported beam loaded at the third points (four-point bending). The addition of steel fibers at high dosages, however, has potential disadvantages in terms of poor workability and increased cost. In addition, due to the high stiffness of steel fibers, microdefects such as voids and honeycombs could form during placing as a result of improper consolidation at low workability levels (Bayasi and Zeng 1993). The two widely used standard test methods are the American standard testing method (ASTM) C 1018: standard test method and the Japan Society of Civil Engineers' (JSCE) standard SF-4 method (Banthia and Nandakumar 2003).

In this work, JSCE SF-4 standard technique has been followed, i.e., the area under the load-deflection plot up to a deflection of span/150 is obtained. From this measure of flexural toughness, a flexural toughness factor (FT) is calculated. It may be noted that FT has the unit of stress such that its value indicates, in a way, the post-matrix cracking residual strength of the material when loaded to a deflection of span/150. The chosen deflection of span/150 for its calculation is purely arbitrary and is not based on serviceability considerations.

Experimental program

Materials

The cement used was OPC 43 grade of specific gravity 3.15. Initial and final setting times of the cement were 140 and 205 min, respectively Indian Standard Designation IS12269-1987 (2003). Fly ash specific gravity was found to be 2.53. Aggregate used was dry and clean, natural, river aggregate. Sizes of aggregates used were 20 and 12 mm. Specific gravity of coarse aggregate was 2.62, and specific gravity of fine aggregate was 2.63.

Mix design

For each cubic meter of concrete, mix proportion given in Table 1 has been adopted and mix designation has been given in Table 2. Mixture design is made in accordance with the Indian standard code 10262–2009 for M20 grade of concrete. Fresh concretes containing 20%, 40%, and 60% fly ash as cement replacement in mass basis were prepared by modifying the reference Portland cement concrete. Fresh fiber-reinforced concretes containing 1.5%, 2.0%, and 2.5% of steel fibers in volume basis were prepared. The procedures for mixing the fiber-reinforced concrete involved the following steps: first, the gravel and sand were placed in a concrete mixer and dry mixed for 1 min. Second, the cement and fiber were spread and dry mixed for 1 min. Third, the mixing water was added and mixed for approximately 2 min. Finally, the freshly mixed fiber-reinforced concrete was cast into specimens mold and vibrated simultaneously to remove any air remain entrapped. After casting, each of the specimens was allowed to stand for 24 h in laboratory before demolding. Demolded specimens were stored in water at 23 ± 2°C until testing days.

Testing methods

For experimental work, cement was replaced by fly ash by 20% and 40% and 60% by mass basis. Steel fibers were added at three different percentages of 1.5%, 2%, and 2.5% (Table 1). Experimental investigation of fresh mix properties of fly ash fiber-reinforced concrete was conducted. Specimens of size 500 × 100 × 100 mm were used to calculate flexural strength and flexural toughness factor. All prisms were tested for flexural strength after 28 days. Flexural testing machine was

Table 2 Mix designation

Mixture number	Fly ash content (%)	Steel fiber content (%)
A1	0	0
A2	0	1.5
A3	0	2
A4	0	2.5
B1	20	0
B2	20	1.5
B3	20	2
B4	20	2.5
C1	40	0
C2	40	1.5
C3	40	2
C4	40	2.5
D1	60	0
D2	60	1.5
D3	60	2
D4	60	2.5

Table 3 Average toughness factor and flexural strength

Mix number	Deflection	Toughness factor	Average toughness factor	Equivalent flexural strength (Mpa)
A1	Center	0.272	0.170	4.12
	L/150	0.08		
	End	0.150		
A2	Center	0.215	0.219	4.20
	L/150	0.243		
	End	0.200		
A3	Center	0.455	0.298	4.68
	L/150	0.193		
	End	0.248		
A4	Center	0.831	0.408	4.82
	L/150	0.408		
	End	0.227		
B1	Center	0.27	0.230	3.84
	L/150	0.21		
	End	0.22		
B2	Center	0.33	0.340	4.10
	L/150	0.35		
	End	0.33		
B3	Center	0.543	0.541	4.56
	L/150	0.546		
	End	0.542		
B4	Center	0.680	0.649	4.84
	L/150	0.684		
	End	0.585		
C1	Center	0.18	0.195	3.17
	L/150	0.27		
	End	0.18		
C2	Center	0.20	0.212	4.15
	L/150	0.17		
	End	0.26		
C3	Center	0.098	0.260	4.48
	L/150	0.29		
	End	0.38		
C4	Center	0.68	0.315	4.75
	L/150	0.12		
	End	0.14		
D1	Center	0.047	0.094	3.05
	L/150	0.16		
	End	0.072		
D2	Center	0.047	0.16	3.89
	L/150	0.16		
	End	0.072		
D3	Center	0.047	0.168	4.11
	L/150	0.16		
	End	0.072		
D4	Center	0.11	0.17	4.19
	L/150	0.13		
	End	0.078		

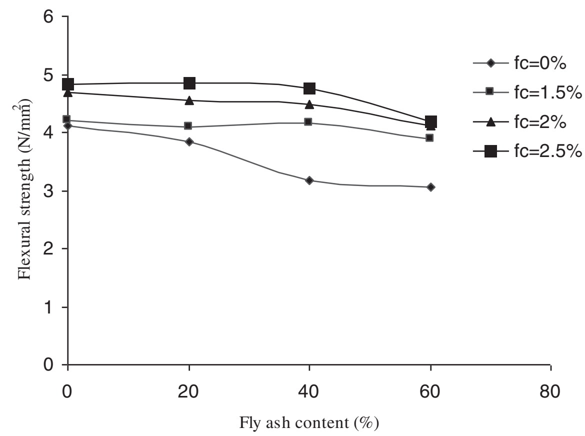

Figure 1 Flexural strength on varying fly ash content.

used to test the specimen. No special care was taken to eliminate the extraneous support settlements from the gross deflections. The applied load and deflection data were recorded manually.

Deflections were measured at the bottom of the specimen near the center and also at the end, and deflections were recorded beyond L/150. The toughness of fiber-reinforced concrete is a measure of the energy absorption capacity of the fibers and is characterized by the area under the load-deflection curve up to a specific deflection. The real effects of fiber addition can be observed as a result of the bridging stress offered by the fibers after the peak load.

Results and discussion

The equivalent flexural strength for four points bending proposed by (JCI) is given by [10] $\sigma b = [Tb \times L]/[\delta\ tb \times b \times h^2]$, where σb is the equivalent flexural strength (N/mm^2); Tb is flexural toughness (N/mm); δ tb is deflection of 1/150 of span (mm); b, d, L is width, depth, and length of section (mm). The toughness and equivalent

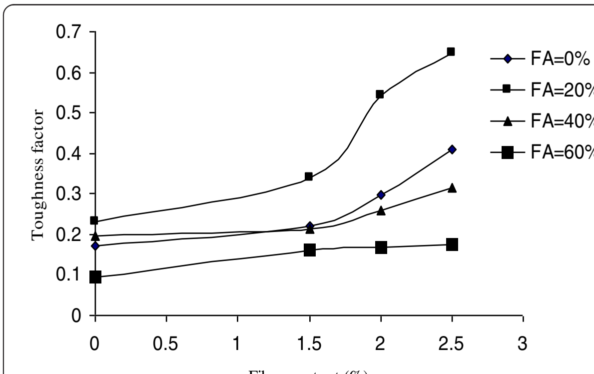

Figure 2 Toughness factor for varying fiber content.

flexural strength values calculated as per JCI specifications for various fiber concretes are given in Table 2, and their respective values are plotted in Figures 1 and 2. Equivalent flexural strength increases as fiber content increases, when 20% fly ash were added the flexural strength values are seems to be higher when compared with 40% fly ash and 60% fly ash content and toughness factor decreases when fly ash content increases.

Conclusions

The following conclusions were made from the tests results:

(1) When 2.5% fibers were added, flexural strength increases by 1.67% compared with that of the conventional concrete.
(2) When fly ash was added in addition to steel fibers, for 20% fly ash + 2.5% fiber equivalent, flexural strength increases by 0.41% compared with that of the 0% fly ash + 2.5% fiber.
(3) Equivalent flexural strength increases as fiber content increases; when 20% fly ash were added, the flexural strength values seem to be higher when compared with that of the 40% fly ash and 60% fly ash content.
(4) Toughness factor decreases by 58% when 60% fly ash + 2.5% fiber were added when compared with that of the 0% fly ash + 2.5% fiber.
(5) When 20% fly ash + 2.5% fiber were added, toughness factor increases by 59% when compared to that of the 0% fly ash + 2.5% fiber; therefore, toughness factor decreases when fly ash content increases.
(6) Therefore, it is concluded that 20% fly ash addition is the optimum dosage when steel fibers are incorporated in concrete.
(7) When fibers are added to fly ash, concrete propagation of cracks are arrested when compared to that of the conventional concrete effectively, which in turn increases flexural strength and toughness.

The characterization of flexural toughness based on the JSCE approach is very simple and is independent of the type of deflection measuring technique. No sophisticated instrumentation is required to determine the toughness factor. The determination of first crack, which is very difficult to identify, is not required in this method. From the results, it is evident that the ductility of fiber-reinforced concrete depends primarily on the fibers' ability to bridge the cracks at high levels of strain. Thus, stiffer fibers would provide better crack bridging; this explains the good performance of steel fibers.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
AS designed the research work, drafted the manuscript, analyze the results and plotted the graphs. KS and GS carried out experiments in the laboratory.

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References
Banthia N, Nandakumar N (2003) Crack growth resistance of hybrid fibre reinforced cement composites. Cem Concr Compos 25:3–9
Bayasi Z, Zeng J (1993) Properties of polypropylene fiber reinforced concrete. ACI Mater J 90:605–610
Bentur A, Mindess S (1990) Fiber reinforced cementitious composites. Elsevier, London
Indian Standard Designation IS12269-1987 (2003) Specification for 53 grade ordinary Portland cement. Bureau of Indian Standards, New Delhi
IS:10262–2000, Recommended Guidelines for Concrete Mix Design. Bureau of Indian Standards (BIS), India
Japanese Concrete Institute, JCI-SF4, Methods of tests for flexural strength and flexural toughness of fiber reinforced concrete (using beam with third-point loading). pp 45–56
Pierre P, Pleau R, Pigeon M (1999) Mechanical properties of steel micro fiber reinforced cement pastes and mortars. J Mater Civil Eng 11:317–324
Qian CX, Stroeven P (2000) Development of hybrid polypropylene–steel fibre-reinforced concrete. Cem Concr Res 30:63–68
Soroushian P, Khan A, Hsu JW (1992) Mechanical properties of concrete materials reinforced with polypropylene or polyethylene fibers. ACI Mater J 89:535–540
Stroeven P, Babut R (1986) Fracture mechanics and structural aspects of concrete. Heron 31(2):15–44
Yao W, Lib J, Wu K (2003) Mechanical properties of hybrid fiberreinforced concrete at low fiber volume fraction. Cem Concr Res 33:27–30

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