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Flexural Behavior of Hybrid Fiber Reinforced High Strength Concrete

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Abstract

Objectives: An experimental study was carried out to study the flexural behavior of high strength concrete of Grade M60 using hooked end steel fibers, polyolefin straight fibers in various volume fractions. **Methods:** Hooked end steel fibers were added into the high strength concrete at volume fraction of 1% and 2%, steel and polyolefin fibers were added 80% - 20% and 60% - 40% combination at each volume fraction in order to cast steel fiber (single) reinforced high strength concrete and hybrid fiber (combination of steel and polyolefin) reinforced high strength concrete specimens. The steel mould of size 100 x100 x 500 mm was used for casting of all specimens. Specimen cast with high strength concrete of grade M60 was treated as a control specimen. Other Specimens were treated as study parameters. **Findings:** All the specimens were tested under third point loading, deflections were measured by using dial gauge at mid span. Deflection ductility calculated from load deflection curve and toughness Indices calculated as per ASTM C 1018-97. The test results Shows that hybrid fiber of volume fraction 2% with Steel 80% -polyolefin 20% combination specimen improves the flexural performance appreciably compared with that of control specimen and steel fiber reinforced high strength concrete specimens. **Applications:** The use hybrid fiber reinforced high strength concrete in structural components investigated by various researchers includes columns, beams, slabs, and beam-column joints. The primary contribution of fibers is in the area of ductility. Hence most of the studies were focused on evaluating the ductility and energy absorption capacity.

Keywords: Ductility, High Strength Concrete, Hybrid Fibers, Toughness

1. Introduction

High - strength concrete is particular where reduced weight is significant or where architectural considerations require smaller load-carrying elements, high strength concrete helps to get more well-organized floor plans through smaller vertical members and has also often established to be the most economical alternative by reducing both the total volume of concrete and the amount of steel required for a structural members[1]. However, high strength concrete when subjected to short term or sustained loads tends to be brittle. This performance of high strength concrete raises questions about the application of the material to structures, mainly in earthquake regions. Addition of fibers in concrete improve the tensile characteristics by inhibiting crack growth and increase in toughness or energy absorption capacity, flexural strength, fatigue resistance and ductility[2,3]. Various types of fibers were used in concrete such as metallic fibers, polymeric fibers, mineral fibers, and naturally occurring fibers, among these steel fibers are giving better performance due to their high modulus of elasticity and tensile strength[4-7]. Concrete with steel fibers have been generally used in the building industry applications such as industrial and airport pavements, reinforcement of projected concrete,

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and precast elements. It has been shown recently that many researchers investigated the mechanical properties of the concept of hybridization with two different fibers incorporated in a common cement matrix, and the hybrid composite can offer more attractive engineering properties, because the presence of one fiber enables the more efficient utilization of the potential properties of the other fiber[8,9]. Hybridization of steel, polypropylene and carbon fibers were focused by the previous researcher. Hence in this study hybridization of hooked end steel and polyolefin straight fibers (80%-20%, and 60%-40%) combination in high strength concrete at 1%, 2% volume fractions were considered. Therefore the objective of this paper is to determine the ductility and toughness Indices of hybrid fiber reinforced high strength concrete by flexural test of specimens. Test results of hybrid fiber reinforced high strength concrete were compared with steel fiber reinforced high strength concrete and plain high strength concrete.

2. Experimental Program

2.1 Materials Used

The cement used in concrete mixes was ordinary portland cement 53 grade as per IS 12269- 1987. The fine aggregate used was local river sand with specific gravity of 2.40. Crushed stone with size of 10 mm, specific gravity of 2.74 coarse aggregate was used. Densified Silica fume is was used for improving the concrete properties in fresh and hardened states. To improve the workability of concrete, a high – range water reducing admixture Gelenium B233 was used. The fibers used in the study were hooked end steel, polyolefin straight fibers, the properties of the fibers are shown in Table 1. The high strength concrete mix proportions were designed with reference to (ACI 211-4R-1993)[10]. The material proportions used for this study is shown in Table 2.

2.2 Preparation of Test Specimens

The specimens of size 100 x 100 x 500 mm square prism were used for flexural strength test. In the preparation of concrete, coarse aggregate, fine aggregate cement and silica fume were initially mixed in dry state. Next the fibers were added manually and maintain uniform distribution by proper dry mixing operations. Then water, the high range water reducing admixture - Gelenium B233 mixed with 50% of required quantity of water was added into the dry mix. The well prepared mix of high strength concrete M60, steel fiber reinforced concrete, (volume fraction V_f-1% and 2%) and at each volume fraction hybrid fiber reinforced concrete specimens were cast with S80%-P20%, S60%-P40% combinations by using the above moulds with proper compaction. The specimens were demoulded after 24 hours and then placed in a curing tank for 28 days.

2.3 Testing Procedure

The flexural strength test was carried out as per ASTM C 78. Testing of specimens were conducted using 200 T capacity of compression testing machine at concrete technology laboratory, the load was increased gradually and the deflections were measured at mid span of specimen with specified load interval by using dial gauge with least count of 0.01 mm per division was used. The deflections were measured after failure of the specimen also, to study the post peak load – deflection curve of the fibrous concrete. The schematic view of the loading set up is shown in Figure 1, and the actual experimental set–up is shown in Figure 2.

Table 1. Properties of fibres used

Fibre Properties	Fiber Details	
	Polyolefin	**Steel**
Length (mm)	54	35
Shape	Straight	Hooked at ends
Size / Diameter (mm)	1.38 x 0.41 mm	0.6 mm
Aspect Ratio	63.68	58.33
Density (kg / m3)	920	7800
Specific Gravity	0.90-0.92	7.8
Young's Modulus (GPa)	10 GPa	210
Tensile strength (MPa)	640 MPa	>1100 Mpa

Table 2. Mix proportions for high strength concrete of grade M60

Materials	Cement	Silica Fume	Fine Aggregate	Coarse Aggregate	HRWR	Water
Power of kg/ m^3	468.48	43.52	594.40	1037.22	6.40	159.50

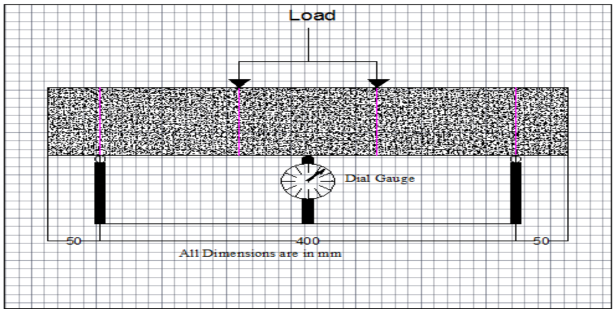

Figure 1. Specimen load set- up details.

Figure 2. Experimental set- up.

3. Results and Discussion

3.1 Ductility

Ductility of a structure is its ability to undergo deformation beyond the initial yield deformation, while still sustaining load. Ductility factor is defined as the ratio of the maximum deflection at any load level to the first yield deflection. The first yield deflection was noted from the load-deflection diagram assuming it as a bilinear diagram. The ductility values were calculated by using the experimental load-deflection curve as shown in Figure 3 and Figure 4 and presented in Table 3.

3.2 Flexural Toughness

The flexural toughness is an important parameter to evaluate the influence of fibers on the post – peak behavior

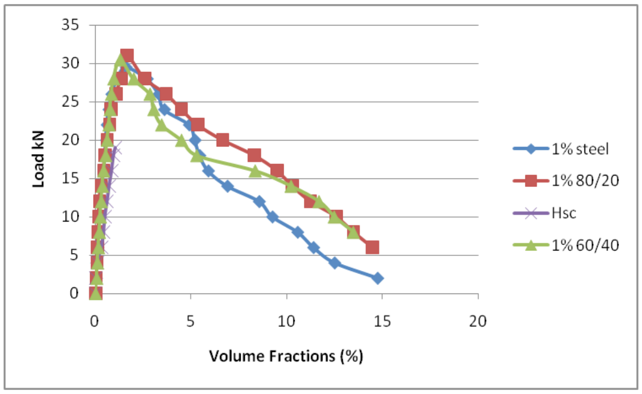

Figure 3. Load deflection curve for 1% volume fractions.

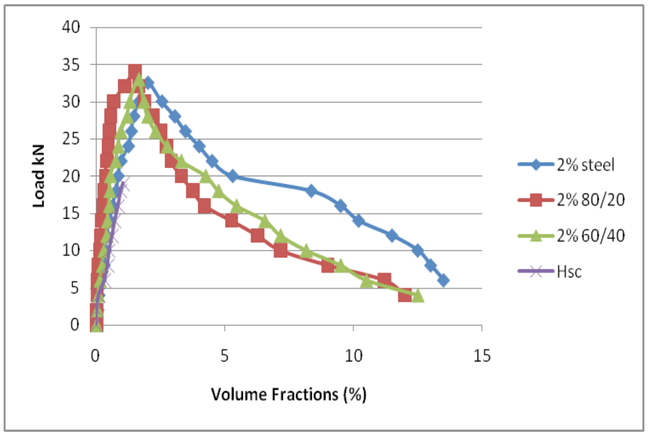

Figure 4. Load deflection curve for 2% volume fraction.

Table 3. Ductility values of specimens

Specimen Name	Volume Fraction (%)	Yield load (kN)	Yield deflection δy(mm)	Ultimate load (kN)	Ultimate Deflection δu (mm)	Deflection Ductility (δu / δy)
HSC	0	18	0.95	19	1.05	1.11
HS1.0 S100 P0	1	28	1.15	29.5	1.6	1.39
HS1.0 S80P20	1	28	1.35	31	1.65	1.22
HS1.0 S60P40	1	28	0.95	30.5	1.1	1.16
HS2.0 S100P0	2	30	1.66	32.5	2	1.20
HS2.0 S80P20	2	30	0.67	34	2.25	3.36
HS2.0 S60/P40	2	30	1.85	33	1.48	0.8

of fiber reinforced concrete. The toughness of fibers-reinforced concrete can be considered as their energy absorption capacity, which is usually characterized by some portion of the area under the load deflection curve obtained during flexure test[11]. The flexural toughness indices possibly calculated as the ratio of the area under the load –deflection curve for the fibrous concrete to specified end points, to the area up to first – crack load. Three indices defined in ASTMC 1018[12] are obtained by dividing the area under the load-deflection curve, determined at a deflection that is a multiple of the first-crack deflection, by the area under the curve up to the first – crack. I_5 is determined at a deflection 3 times the first crack deflection, I_{10} is determined at 5.5 and I_{30} at 15.5 times the first crack deflection. In this study toughness indices were calculated by using the experimental load deflection curve as shown in Figure 3 and Figure 4. Toughness indices values are shown in Table 4. These indices increased their values with increasing volume fraction of steel and polyolefin fibers. It shows high – strength hybrid fibrous concrete values were more than the high – strength concrete with steel fibers at each volume fraction. The maximum value of toughness Indices values are 7.34, 18.35, 38.46 for I_5, I_{10}, I_{30} respectively for 2% volume fraction with 80%-20% (HS2.0 S80P20) combination of steel and polyolefin.

Table 4. Flexural toughness indices values

Specimen Name	Fiber volume fraction Vf (%)	Toughness Indices		
		I_5	I_{10}	I_{30}
HSC	0	1	1	1
HS1.0 S100 P0	1	4.66	11.65	24.42
HS1.0 S80P20	1	4.96	12.40	25.99
HS1.0 S60P40	1	4.63	11.58	24.26
HS2.0 S100P0	2	7.14	17.85	37.41
HS2.0 S80P20	2	7.34	18.35	38.46
HS2.0 S60/P40	2	7.22	18.05	37.83

3.3 Crack Resistance of Specimens

Fibers influence the mechanical properties of concrete in all failure modes, especially those that induce fatigue, direct tension, bending, impact, and shear. The strengthening mechanism of the fibers involves transfer of stress from the matrix to the fiber by interfacial shear or by interlock between the fiber and matrix if the fiber surface is deformed. Stress is thus shared by the fiber and matrix in tension until the matrix cracks, and then the total stress is progressively transferred to the fibers[13,14]. The crack pattern of fiber and hybrid fiber reinforced concrete specimen after failure is shown in Figure 5. It shows that the fibers are resisting the crack formation even after failure.

Figure 5. Crack patterns of specimens after failure.

4. Conclusions

From the experimental study the following conclusions can be made the ultimate load is increased with increase in fiber content, maximum load was 34 kN attained by the HS2.0 S80P20 specimen.

Deflection ductility is increased with increase in fiber content; maximum values were obtained by 2% volume fraction 80% -20% combination specimen. Toughness index values were increased with increase in fiber content up to 2% volume fraction with 80% -20% combination of steel and polyolefin fiber. The steel fiber and hybrid fiber composition were act as bridging of cracks even after failure of the specimen.

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