STRENGTH AND DUCTILITY PERFORMANCE OF POLYOLEFIN-BASALT HYBRID FIBRE REINFORCED CONCRETE BEAMS

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ABSTRACT

This paper presents a study on the effect of fibre content on the strength and ductility of hybrid fibre reinforced concrete beams having different fibre volume fractions was investigated. The hybridization of different types of fibres may play important roles in arresting cracks at various levels. Hybrid fibre reinforced concrete beams incorporated with 30% polyolefin and 70% basalt fibres with a total fibre volume fraction V_f ranged from 0.0 to 2.0% with 0.5 % interval. The study parameters of this investigation includes service load, yield and ultimate load, service load deflection, yield and ultimate load deflection, ductility, crack width and failure modes. The strength, deformation and ductility performance of hybrid fibre reinforced concrete beams was compared with that of reference beam. The test results indicate that addition of 1.5% by volume of hybrid fibres enhance their overall performances.

Keywords: basalt fibre, deformation, ductility, polyolefin fibre, strength.

INTRODUCTION

Modern construction industry demands increased performance from construction materials, in terms of strength, toughness, ductility and durability. Construction of tall buildings, long span bridges, seismic resistant structures, durable pavement and offshore structures require higher performance from all the materials, especially concrete. Improvements to the properties of concrete can be achieved by several means which includes addition of fibres.

Reinforcement of concrete with short randomly distributed fibres can address some of the concerns related to concrete brittleness and poor resistance to crack growth. [1-3]. Fibres used as secondary reinforcement in concrete is mainly to inhibit crack initiation and propagation [4]. Most of the Fibre Reinforced Concrete (FRC) used today involves the use of a single type of fibre. The gradual and multi-scale nature of fracture in concrete implies that a given fiber can provide reinforcement only at one level, and within a limited range of strains [5-6]. It has been shown recently that the hybrid composite can offer more attractive engineering properties, because, the presence of one fibre enables more efficient utilization of the potential of the other.

One idea gaining much attention lately is that of fiber hybridization. In a hybrid, two or more different types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response which provides new and superior properties within the material like improved elastic modulus, ductility, light weight and flame retarding ability [7-10]. As for the structural properties of the basalt fiber, several reports are available which show promising capacity of the material. Previously, basalt was a preferred choice of material (as fibres) in the construction industry, and has been in extensive use since as an external or internal reinforcement within concrete materials [11-14]. The basic purpose of using fibres is to control cracks at different size levels, in different zones of concrete (cement paste or interface zone between paste and aggregate), at different curing ages and at different loading stages [15]. Although the fibre reinforced concrete has been widely used in practice and a bulk of research studies have been reported, the effect of hybrid fibres on the performance of reinforced concrete beams has not yet been fully explored. This research work focuses on Hybrid Fibre Reinforced Concrete (HFRC) beams with polyolefin-basalt hybrid fibres. In this system, basalt fibre improves the first-crack strength and ultimate strength, while, the polyolefin fibre is expected to improve toughness and strain capacity in the post-cracking zone [16]. The main purpose of this study is to evaluate the strength and ductility performance of reinforced concrete beams with polyolefin and basalt fibres

EXPERIMENTAL PROGRAM

Materials

Cement concrete having cube compressive strength of 26.65 MPa was used for casting beams. Two nos. of mm diameter HYSD bars were used as longitudinal reinforcement and 8 mm diameter 2-legged stirrups spaced at 120 mm c/c were used as shear reinforcement. Table-1 shows the properties of fibres used in the experimental work.

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Table-1. Properties of fibres.

S. No	Fibre properties	Fibre type	
		Polyolefin	Basalt
1	Length (mm)	48	18
2	Size (mm)	0.73	1.0
3	Density (kg/m^3)	920	2750
4	Specific Gravity	0.92	2.7
5	Young's Modulus (GPa)	6.0	80.5
6	Tensile strength (MPa)	550	4400

Specimen details

A total of five beams were cast and tested in this study. The test program was designed to study the strength and ductility performance of reinforced concrete beams with and without fibres. All the beams were rectangular in cross-section. They were 150 mm wide, 250 mm deep and the overall length was 3000 mm. A reinforced concrete beam HB0- P0 B0 was used as reference beam. The proportion of P (polyolefin) and B (basalt) being 30% - 70% for all the beam specimens. The total fibre volume fraction was varied from 0 to 2%, with 0.5% increase. Table-2 shows summary of tested beam.

Table-2. Summary of tested beam.

S. No.	Beam specification	Fibre volume fractio, V_f, (%)	Proportion of fibres (%)		Beam dimension	Tensile steel ratio (%)	Beam type
			Polyolefin	Basalt			
1	HB 0-P0 B0	0	0	0	150 × 250 ×3000	0.60	Beams without Fibres.
2	HB 0.5-P30 B70	0.5	30	70			Beams with 0.5% Fibre volume fraction
3	HB 1.0-P30 B70	1.0	30	70			Beams with 1.0 % Fibre volume fraction
4	HB 1.5-P30 B70	1.5	30	70			Beams with 1.5% Fibre volume fraction
5	HB 2.0-P30 B70	2.0	30	70			Beams with 2.0% Fibre volume fraction

Preparation of test beam

A tilting type drum mixer was used for mixing fresh concrete. The cement, sand and coarse aggregate were placed inside the wet drum and then dry mixed. To this dry mixture, 80% of the water and 60% of the Superplastizer (High range water reducing admixture-Conplast@ SP337) were added slowly and mixed thoroughly. Fibres were then added slowly and evenly along the walls of the drum to avoid formation of fibre balls and clustering. The remaining water and superplastizer were finally added slowly to the mixture and mixed. The beam specimens were cast using steel moulds. Care was taken to see that the concrete was properly placed in the moulds and compacted uniformly using needle vibrator. The beam specimens were demoulded after 24 hours of casting and cured in a standard manner. The beam specimens were cast in batches. Control specimens were also cast simultaneously along with each test beam.

Testing procedure

All the beams were tested under four-point bending in a loading frame of 500 kN capacity. The beams had 100 mm bearing on both ends, resulting in attest span of 2800 mm. Two point loads were applied through a spreader beam. The deflections were measured at mid-span and load points using mechanical dial gauges of 0.01 mm accuracy. The crack widths were measured using a crack deflection microscope with a least count of 0.02 mm. All the above measurements were taken at different load levels until failure. Further, mode of failure was also observed. Figure-1 shows a photographic view of the set-up showing the instrumentation used.

Figure-1. Photographic view showing instrumentation used.

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RESULTS AND DISCUSSIONS

The principal test results are presented in Table-3 and typical load-deflection curves of the beams are shown in Figure-3. The test result show that the load and deformation capacity increases with increase in fibre content up to 1.5% after that gets reduced. The increase in yield load as 57.6%, service and ultimate load was up to be 54.5% when compared to the referenced beam. The load comparison of tested beam shown in Figure-2. The increase in service, yield and ultimate deformation was found to be 188.16 %, 59.83% and 143.75 % respectively. When compared to the reference beam.

Table-3. Principal test results of beams.

S. No.	Beam Specification	Service load (kN)	Service load deflection (mm)	Yield load (kN)	Yield load deflection (mm)	Ultimate load (kN)	Ultimate deflection (mm)	Crack Width (mm)
1	HB 0-P0 B0	30.55	4.90	39.24	12.1	45.83	32.0	0.64
2	HB 0.5-P30 B70	38.89	11.46	48.54	18.02	58.33	61.6	0.42
3	HB 1.0-P30 B70	41.67	13.50	57.50	18.96	62.50	72.0	0.36
4	HB 1.5-P30 B70	47.22	14.12	61.84	19.34	70.83	78.0	0.28
5	HB 2.0-P30 B70	42.47	13.76	58.70	19.04	63.70	70.5	0.32

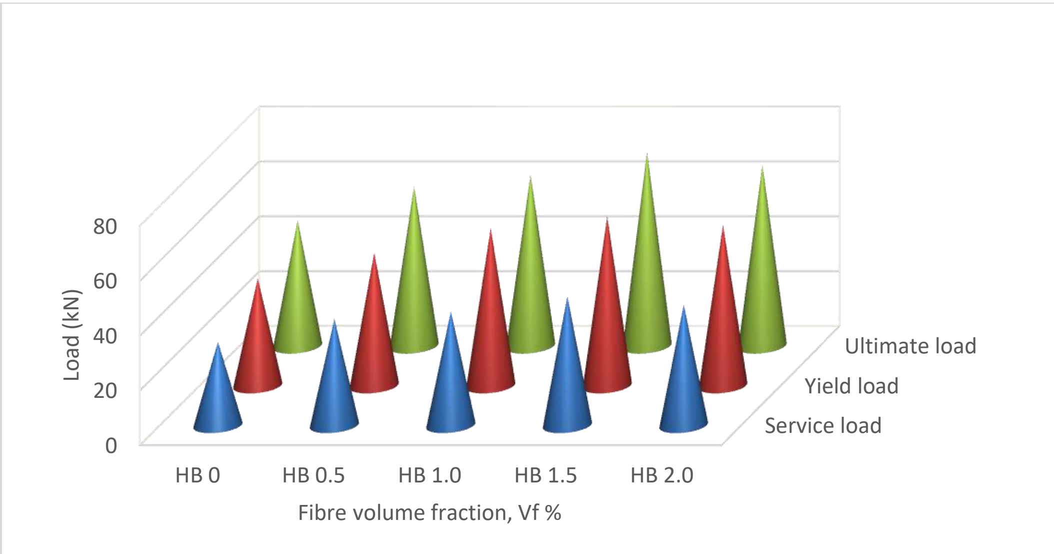

Figure-2. Load combination of tested beams.

Load-Deflection behaviour

From Table-3 and Figure-3 it was observed that the load carrying capacity increases with increase in fibre content up to 1.5% after that the value gets reduced. The maximum increase in ultimate load and deflection was found to be 54.55% and 143.75% with 1.5% fibre content when compared to that of reference beam. Typical load-deflection curves of the beams are shown in Figure-3.

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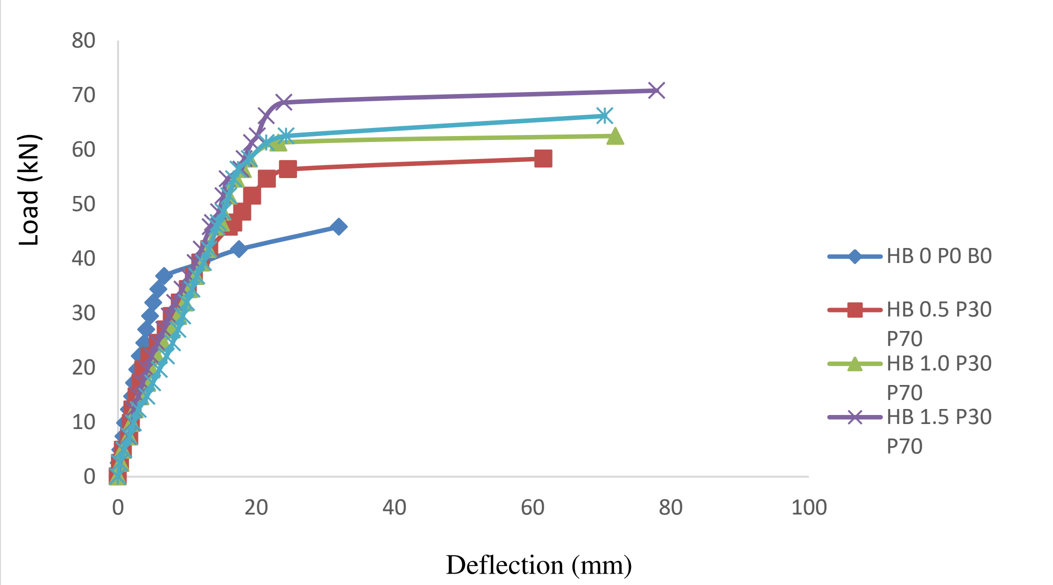

Figure-3. Load-deflection behaviour of beams.

Effect on ductility

The ductility ratios of tested beams are presented in Table-4. It indicates that beams without fibres exhibit little ductility. It was noticed that the beam with fibres failure was not sudden. The randomly oriented fibres crossing the cracked reaction resisted the propagation of cracks and separation of the section. This causes an increase in the loading capacity beyond the first cracking. The increase in deformation ductility was found to be up to 52.7% with 1.5% compared to the reference beams. Ductility of tested beams in shown Figure-4.

Table-4. Ductility ratio of test beams.

S. No.	Beam Specification	Deflection Ductility	Energy Ductility	Deflection Ductility Ratio	Energy Ductility Ratio
1	HB 0-P0 B0	2.64	3.09	1.00	1.00
2	HB 0.5-P30 B70	3.42	4.11	1.29	1.33
3	HB 1.0-P30 B70	3.80	4.13	1.44	1.34
4	HB 1.5-P30 B70	4.03	4.62	1.53	1.49
5	HB 2.0-P30 B70	3.70	4.02	1.40	1.30

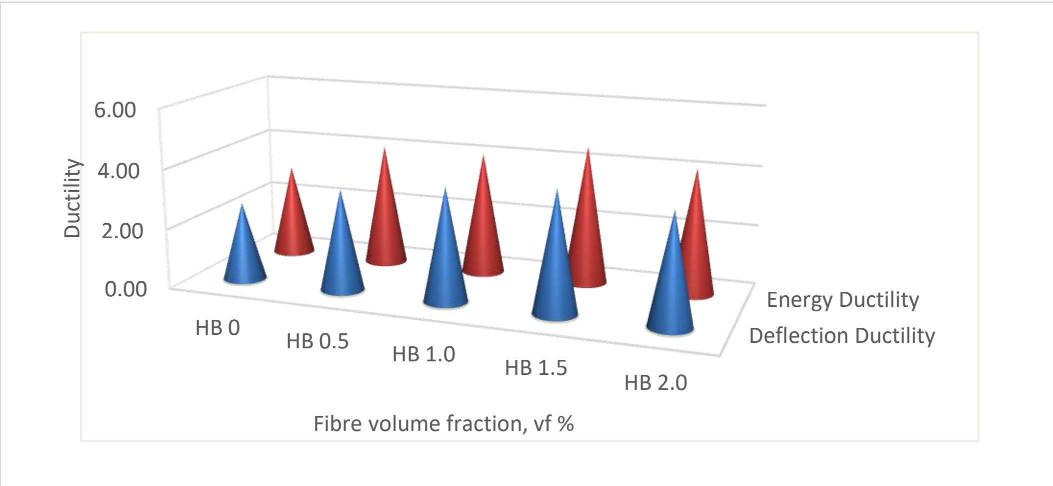

Figure-4. Ductility of tested beams.

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Effect on crack width

From the test results furnished in Table-3, it can be seen that the reinforced concrete beams with hybrid fibres exhibit decrease in crack width with increase in fibre content up to 1.5% after that the value gets increased. The maximum reduction in crack width was found to be 56.3% with 1.5% fibre content when compared to that of reference beam. Figure-5 shows the crack width behaviour of the beams with and without fibres.

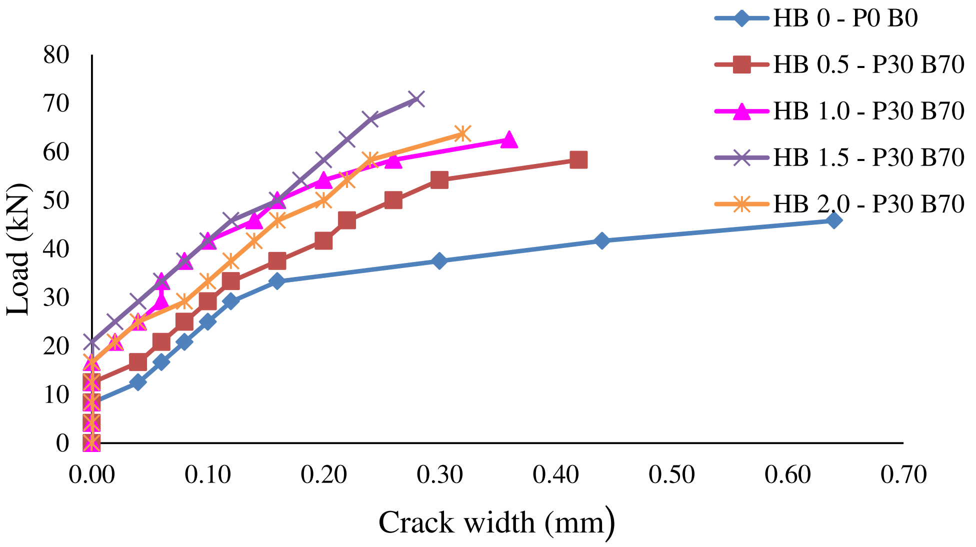

Figure-5. Crack width behaviour of beams with and without fibres.

Failure mode of beams

The failure pattern of as tested beams are shown in Figures (6-10) and their salient details at failure is given in Table-5. In this study all the beam specimens. It can be seen that the beam HB 0- P0 B0 has failed by local concrete crushing (Figure-6). This mode of failure was modified into a ductile mode of failure in HFRC beams.

Table-5. Failure modes of tested beam.

S. No.	Beam Specification	Mode of failure
1	HB 0-P0 B0	Crushing
2	HB 0.5-P30 B70	Flexural
3	HB 1.0-P30 B70	Flexural
4	HB 1.5-P30 B70	Flexural
5	HB 2.0-P30 B70	Flexural

Figure-6. Failure mode of reference beam.

Figure-7. Failure mode of HB 0.5- P30 B70.

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Figure-8. Failure mode of HB 1.0 - P30 B70.

Figure-9. Failure mode of HB 1.5 - P30 B70.

Figure-10. Failure mode of HB 2.0 - P30 B70.

CONCLUSIONS

- A fibre volume fraction of 1.5% with 30% and 70% polyolefin-basalt hybrid fibres significantly improves the strength, deformation and ductility performance of reinforced concrete beams.
- Hybrid fibre enhances the strength and deformation capacity of reinforced concrete beams. The maximum increase in ultimate load 54.55% and increase in deflection to the tune of 143.75 % in comparison with the reference beam.
- Hybrid fibre enhances the ductility of reinforced concrete beams. The increase in deflection ductility was found to be 1.53 times than that of reference beam.
- The maximum reduction in crack width was found to be 56.3% when compared to that of reference beam.
- All the beam specimens failed in flexure mode only. Mode of failure gets modified to ductile in beams with fibres, when compared to a typical brittle failure in reference beam.

CONFLICTS OF INTEREST

The authors do not have any conflict of interest with other entities or researchers.

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