Journal of Urban and Environmental Engineering, v.11, n.2, p.174-179

ISSN 1982-3932
doi: 10.4090/juee.2017.v11n2.174179

Journal of Urban and Environmental Engineering
www.journal-uee.org

DUCTILITY RESPONSE OF HYBRID FIBRE REINFORCED CONCRETE BEAMS

Eswari Natarajan

Department of Civil Engineering, Pondicherry Engineering College, India

Received 12 August 2016; received in revised form 10 September 2017; accepted 15 September 2017

Abstract: The effect of fibre content on the Strength and ductility behaviour of hybrid fibre reinforced concrete (HFRC) beams having different fibre volume fractions was investigated. The parameters of this investigation included service load, ultimate load, service load deflection, ultimate load deflection, crack width, deflection ductility and energy ductility. The fibre volume fraction (V_f) ranged from 0.0 to 2.0 percent. Steel and polyolefin fibres were combined in different proportions and their impact on the above parameters was studied. The ductile response of hybrid fibre reinforced concrete beams was compared with that of control beam. The test results show that addition of 2.0 percent by volume of hybrid fibres improve the strength and ductility appreciably. Empirical expressions for predicting the strength and ductility of hybrid fibre reinforced concrete (HFRC) are proposed based on regression analysis. A close agreement has been obtained between the predicted and experimental results.

Keywords: Ductility; Fibres; Flexure; Hybrid fibre reinforced concrete; Regression; Steel fibre reinforced concrete; Strength.

INTRODUCTION

Plain concrete is a brittle material with low tensile strength and poor fracture toughness. The tensile strength of concrete is very low because plain concrete normally contains numerous micro-cracks. Addition of fibres to concrete transforms it from a brittle to a more ductile material (ACI Committee (544), 1989; Qureshi *et al*., 2013.

Fibre reinforced concrete specimens, unlike that of their counterparts, which fail at the point of ultimate flexural strength or the first crack, do not fail immediately after the initiation of the first crack. After the first crack, the load is transferred from the concrete matrix to the fibres (Banthia & Nandakuma, 2003; Hameed *et al*., 2010). For an optimal response, different types of fibres may be suitably combined to produce hybrid fibre reinforced concrete (HFRC). This research work focuses on the polyolefin – steel hybrid fibre reinforced system. In this system, steel fibre, which is stronger and stiffer, improves the first crack stress and ultimate strength, while polyolefin fibre, which is more flexible and ductile, leads to improved strain capacity and toughness in the post-cracking zone (Ramakrishnan, 2000; Blunt & Ostertag, 2009). Such improvements are made possible by the ability of fibres to modify the failure mechanisms of the composite material. These improvements depend on the type, aspect ratio and volume fraction of fibres as well as the quality of concrete mix (Shah, 1987).

Most of the fibre reinforced concrete used today involves the use of a single fibre type. 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 properties of the other fibre (Banthia & Soleimani, 2005; Yao *et al*., 2002). Information available on the strength and ductility of hybrid fibre reinforced concrete beams is still limited. Hence an attempt has been made to study the strength and ductility of hybrid fibre reinforced concrete (HFRC) beams.

RESEARCH SIGNIFICANCE

The present research investigation is intended to address three major concerns. The first is to explore the possibility of using hybrid fibres system for improved performance of reinforced concrete beams. The second is to examine the enhancement in flexural capacity of hybrid fibre reinforced concrete beams. The third is to evaluate the ductility of the hybrid fibre reinforced concrete beams.

EXPERIMENTAL PROGRAMME

Specimen details

A total of seventeen beams were tested in flexure. The test programme was designed to study the strength and ductility of fibre 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. **Table 1** shows the details of the specimens used for testing.

Material Properties

Cement concrete having cube compressive strength of 26.65 MPa was used for casting the specimens. 2 nos. of 12 mm diameter HYSD bars were used as longitudinal reinforcement. 8mm diameter 2-legged stirrups at 120 mm c/c were used as shear reinforcement. **Table 2** shows the properties of fibres used in the experimental work.

TESTING OF BEAMS

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 a test span of 2800 mm. Two point loads through a spreader beam were applied. The deflections were measured at mid span and load points using mechanical dial gauges of

Table 1. Details of tested beams

Beam designation	Fibre content V_f (%)	Type of fibre	
		Polyolefin	Steel
H0 – P0 S0	0	0	0
H0.5 – P0 S100	0.5	0	100
H0.5 – P20 S80	0.5	20	80
H0.5 – P30 S70	0.5	30	70
H0.5 – P40 S60	0.5	40	60
H1 – P0 S100	1.0	0	100
H1 – P20 S80	1.0	20	80
H1 – P30 S70	1.0	30	70
H1 – P40 S60	1.0	40	60
H1.5 – P0 S100	1.5	0	100
H1.5 – P20 S80	1.5	20	80
H1.5 – P30 S70	1.5	30	70
H1.5 – P40 S60	1.5	40	60
H2 – P0 S100	2.0	0	100
H2 – P20 S80	2.0	20	80
H2 – P30 S70	2.0	30	70
H2 – P40 S60	2.0	40	60

H0 – P0 S0: Reference beam

Table 2. Properties of fibres

Fibre properties	Fibre details	
	Polyolefin	Steel
Length (mm)	48	30
Shape	Straight 	Hooked ends 
Size/Diameter (mm)	1.22×0.732	0.5
Aspect Ratio	39.34	60
Density (kg/m^3)	920	7850
Young's Modulus (GPa)	6	210
Tensile strength (MPa)	550	532

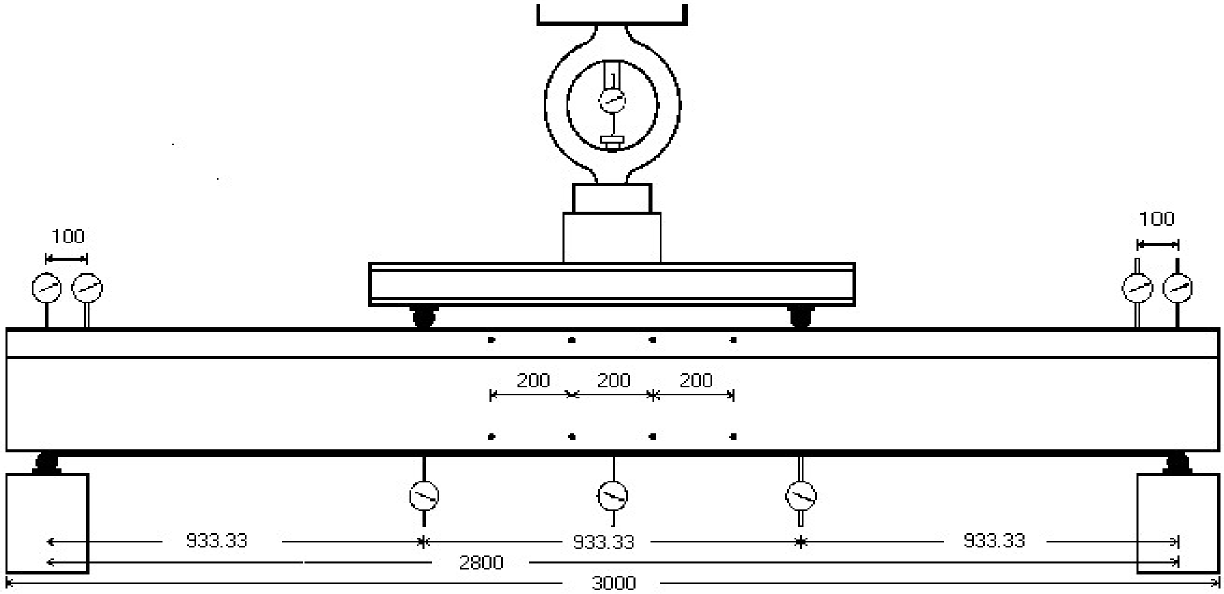

Fig. 1 Test setup and instrumentation.

0.01 mm accuracy. Two dial gauges were mounted on the compression face of the specimen over supports to measure slope at both ends.

The deflection at ultimate load level was also measured using a specially designed mechanical dial gauge. The surface strains at extreme fibres were measured using a Demec gauge. The crack widths were measured using a crack detection microscope with a least count of 0.02 mm. Crack development and propagation was monitored during the process of testing. All the above measurements were taken at different load levels until failure. The details of instrumentation are shown in **Fig. 1**.

MULTIVARIATE LINEAR REGRESSION

Multivariate linear regression involves more than one independent variable to predict the value of the dependent variable. The basic formulation of multivariate linear regression equation is:

$$\begin{Bmatrix} \frac{\partial}{\partial a_0} \\ \frac{\partial}{\partial a_1} \\ \frac{\partial}{\partial a_2} \\ \frac{\partial}{\partial a_3} \\ \vdots \\ \frac{\partial}{\partial a_n} \end{Bmatrix} \sum_{i=1}^{K} \left(P_i - \left(a_0 + a_1 x_{1i} + a_2 x_{2i} a_3 x_{3i} + \cdots + a_n x_{ni}\right)\right) = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 0 \end{Bmatrix} \quad (1)$$

where, $a_0 \cdots a_n$ are the coefficients to be determined, $x_1 \cdots x_n$ are the independent variables, P is the dependent variable or the actual result value for the set of i^{th} input data and K is the number data sets available for regression. On executing the partial derivative operators, equation 1 reduces to:

$$\sum_{i=1}^{K} \begin{bmatrix} 1 & x_{1i} & x_{2i} & x_{3i} & \cdots & x_{ni} \\ x_{1i} & x_{1i}^2 & x_{1i}x_{2i} & x_{1i}x_{3i} & \cdots & x_{1i}x_{ni} \\ x_{2i} & x_{2i}x_{1i} & x_{2i}^2 & x_{2i}x_{3i} & \cdots & x_{2i}x_{ni} \\ x_{3i} & x_{3i}x_{1i} & x_{3i}x_{2i} & x_{3i}^2 & \cdots & x_{3i}x_{ni} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{ni} & x_{ni}x_{1i} & x_{ni}x_{2i} & x_{ni}x_{3i} & \cdots & x_{ni}x_{ni} \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_n \end{Bmatrix} = \sum_{i=1}^{K} \begin{Bmatrix} P_i \\ P_1 P_i \\ P_2 P_i \\ P_3 P_i \\ \vdots \\ P_n P_i \end{Bmatrix} \quad (2)$$

The above equation can be solved by summing up the values of independent and dependent variables after carrying out the required operations.

RESULTS AND DISCUSSION

Effect on Strength

The principal test results are presented in **Table 3**. The loads carried by all the test beams at service stage and at ultimate stage were obtained experimentally. It can be inferred from the test results furnished in **Table 3** that the load carrying capacity increases with increase in fibre content. The increase in service and ultimate load was found to be 74% and with 2.0% fibre content when compared to the reference beam and 51% when compared with specimens consisting of 100% steel fibres.

Table 3 Data used in regression analysis for tested beams

Beam specification	Service stage			Ultimate stage		
	Service load (kN)	Mid span deflection (mm)	Crack width (mm)	Ultimate load (kN)	Mid span deflection (mm)	Crack width (mm)
H0 – P0 S0	27.79	5.65	0.14	41.69	30	0.58
H0.5 – P0 S100	33.25	8.25	0.12	49.87	56	0.28
H0.5 – P20 S80	34.33	9.31	0.11	51.50	62	0.30
H0.5 – P30 S70	35.43	10.10	0.12	53.14	71	0.29
H0.5 – P40 S60	37.06	11.82	0..11	55.59	80	0.29
H1 – P0 S100	35.20	9.37	0.12	52.80	59	0.27
H1 – P20 S80	35.43	9.58	0.12	53.14	66	0.30
H1 – P30 S70	36.60	10.12	0.11	54.90	72	0.30
H1 – P40 S60	37.60	11.98	0.11	56.40	84	0.31
H1.5 – P0 S100	35.97	9.12	0.09	53.95	65	0.26
H1.5 – P20 S80	36.20	9.91	0.11	54.30	70	0.30
H1.5 – P30 S70	36.64	10.36	0.11	54.96	78	0.30
H1.5 – P40 S60	39.30	12.14	0.12	58.95	90	0.31
H2 – P0 S100	41.97	9.48	0.08	62.95	71	0.25
H2 – P20 S80	42.15	10.48	0..09	63.22	78	0.29
H2 – P30 S70	47.41	10.68	0.10	71.11	86	0.30
H2 – P40 S60	48.36	13.19	0.11	72.96	98	0.31

Effect on Deformation

The deflections at different load levels of the test beams are presented in **Table 4**. The deflection characteristics of the reinforced concrete beams improved much with the addition of fibres. These influences were more pronounced for reinforced concrete beams with hybrid fibres. The increase in service load deflection and ultimate load deflection was found to be 133.45%, and 226.67% respectively with 2% hybrid fibre content when compared to the reference beam and 67.78% and 136.67% when compared with specimens consisting of 100% steel fibres.

Effect on Crack Width

The reduction in crack width was found to be 42.85% and 56.90% respectively at service and at ultimate load level with 2% steel fibres when compared to the reference beam. The reduction in crack width was found to be 35.71% and 50% respectively at service and at ultimate load level with 2% hybrid fibres when compared to the reference beam.

Effect on Ductility

Ductility of a beam is its ability to sustain inelastic deformation without any loss in its load carrying, prior to failure (You *et al*., 2011; Soroushian *et al*., 1993). Ductility can be expressed in terms of deformation or energy. The deformation can be deflection, strain or curvature. It can be inferred from the results presented in **Table 4** that the hybrid fibre reinforced concrete beams exhibit enhanced ductility than that of the reference beam.

The increase in deflection and energy ductility was found to be 73.5% and 191.34% respectively with 2.0% hybrid fibre content when compared to the reference beam and 9.26% & 35.79% when compared with specimens consisting of 100% steel fibres. The enhancement in deflection and energy ductility for beams with and without fibres are shown in **Figs 2–3.**

Regression Modelling

The regression equations have been proposed for predicting the study parameters. The data used for regression analysis are presented in **Table 5**. Predictions from the regression equations were compared against experimental results. It has been found that the multivariate linear regression can make a reasonable estimate on the prediction values for service load, ultimate load, service deflection, ultimate deflection, crack widths, deflection ductility and energy ductility. A close agreement has been obtained between the predicted and experimental results.

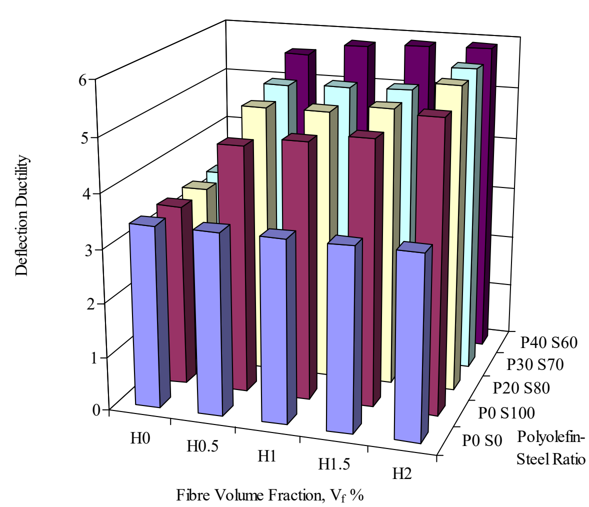

Fig. 2 Deflection ductility for beams with and without fibres.

Table 5. Regression equations for tested beams.

Parameter	Equation	Fitness	RMS Error
Service Load (kN)	$29.67+717.90V_f+552.05V_p-213.64V_s$	0.81	2.15
Service Load Deflection (mm)	$8.54-58.94V_f+565.82V_p+84.79V_s$	0.60	1.05
Crack Width at service load (mm)	$0.13-1.72V_f+2.42V_p-0.54V_s$	0.71	0.007
Ultimate Load (kN)	$P_n=6x\left(A_s f_y\left(d-\frac{a}{2}\right)+\sigma_t b(h-e)\left(\frac{h}{2}+\frac{e}{2}-\frac{a}{2}\right)+\sigma_p b(h-e)\left(\frac{h}{2}+\frac{e}{2}-\frac{a}{2}\right)\right)/L$ where $\sigma p=0.0568\frac{l_p}{d_p}\rho_p f_{bep}$	0.81	3.25
Ultimate Load Deflection (mm)	$52.64+732.14V_f+4082.71V_p-26.49V_s$	0.73	7.78
Crack Width at Ultimate load (mm)	$0.38-20.82V_f+20.01V_p+13.19V_s$	0.32	0.06
Deflection Ductility	$4.49+28.58V_f+126.26V_p+7.63V_s$	0.60	0.37
Energy Ductility	$1.32+8.71V_f+37.33V_p+2.06V_s$	0.61	0.11
Deflection Ductility Ratio	$8.93-159.30V_f+916.12V_p+290.60V_s$	0.78	1.18
Energy Ductility ratio	$1.65-29.23V_f+168.41V_p+53.56V_s$	0.78	0.218

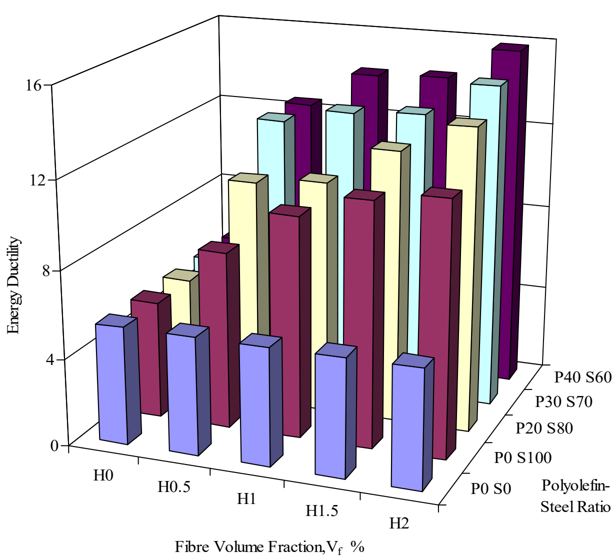

Fig.3 Energy ductility for beams with and without fibres.

Table 4. Ductility ratios of hybrid fibre reinforced concrete beams.

Beam specification	Deflection ductility	Deflection ductility ratio	Energy ductility	Energy ductility ratio
H0 – P0 S0	3.40	1.00	5.43	1.00
H0.5 – P0 S100	4.63	1.36	8.14	1.50
H0.5 – P20 S80	5.05	1.48	10.43	1.92
H0.5 – P30 S70	5.21	1.53	12.47	2.30
H0.5 – P40 S60	5.57	1.64	12.50	2.30
H1 – P0 S100	4.80	1.41	10.16	1.87
H1 – P20 S80	5.06	1.49	10.74	1.98
H1 – P30 S70	5.25	1.54	13.13	2.42
H1 – P40 S60	5.80	1.70	14.17	2.61
H1.5 – P0 S100	4.95	1.45	11.22	2.07
H1.5 – P20 S80	5.20	1.53	12.48	2.30
H1.5 – P30 S70	5.28	1.55	13.34	2.46
H1.5 – P40 S60	5.87	1.73	14.31	2.64
H2 – P0 S100	5.40	1.59	11.65	2.15
H2 – P20 S80	5.70	1.68	13.85	2.55
H2 – P30 S70	5.75	1.69	14.92	2.75
H2 – P40 S60	5.90	1.74	15.82	2.91

CONCLUSIONS

(a) A hybrid fibre volume fraction of 2.0% with 40-60 Polyolefin-Steel combine significantly improves the overall performance of reinforced concrete beams.

(b) An overall evaluation of the flexural test results indicates that hybrid fibre reinforced concrete exhibit higher load carrying capacity and deformation capacity. The increase in ultimate load was found to be 75% when compared to the reference beam and 51% when compared to specimens consisting of 100% steel fibres. The increase in ultimate deflection was found to be 3.27 times than that of reference beam and 1.38 times than that of specimens consisting of 100% steel fibres.

(c) The fibre reinforced concrete beams exhibit more number of cracks with lesser widths at all load levels when compared to the reference beam. The maximum reduction in crack width at ultimate load level was found to be 56.90% when compared to the reference beam and 50% when compared to specimens consisting of 100% steel fibres.

(d) The HFRC beams exhibit enhanced ductility than the reference beam. The increase in deflection and energy ductility was found to be 1.74 & 2.91times than that of reference beam and 1.09 & 2.15 times than that of specimens consisting of 100% steel fibres.

(e) Regression equations for predicting the strength and ductility of hybrid fibre reinforced concrete are proposed. A close agreement has been obtained between the predicted and experimental results.

Acknowledgement The authors wish to acknowledge the financial support offered by Tamilnadu State Council for Science and Technology (TNSCST), Chennai, for carrying out this research investigation at Annamalai University. The authors also wish to thank Elasto-Plastic Concrete (Europe) Ltd., and Bekaert Fibre Technologies, Belgium for their support by way of providing polyolefin fibres and Dramix steel fibres for carrying out the research work.

REFERENCES

ACI Committee (544) (1989) Measurement of Properties of Fibre Reinforced Concrete, (ACI 544.2R-889), American Concrete Institute, Detroit, Michigan, USA.

Banthia, N. & Nandakuma, N. (2003) Crack Growth Resistance of Hybrid Fibre Reinforced Cement Composites, *Cement and Concrete Composites*, **25**, 3-9.

Banthia, N. & Soleimani, S.M. (2005) Flexural Response of Hybrid Fibre-Reinforced Cementitious Composites, *ACI Materials Journal*, **102**(6), 382-389.

Blunt, J.D. & Ostertag, C.P. (2009) Deflection Hardening and Workability of Hybrid Fiber Composites. *ACI Materials Journal*, **106**(3), 265-272.

Hameed, R., Turatsinze, A., Duprat, F., & Sellier, A. (2010). Study on the flexural properties of metallic- hybrid fibre reinforced concrete. *Maejo International Journal of Science and Technology*, **4**(2), 169-184.

Qureshi, L.A., Sheikh, M.I. & Sulthan, T. (2013). Effect of Mixing Fiber Cocktail on Flexural Strength of Concrete. *Systems Engineering Procedia*, **54**, 711-719. doi: 10.1016/j.proeng.2013.03.065

Ramakrishnan,V. (2000) Construction of Highway Structures with Synthetic Structural Fibre Reinforced Concrete, ICFRC, *Proceedings of the High Performance Concrete Composites,* India 1-17.

Shah, S.P. (1987) Strength Evaluation and Failure Mechanisms of Fibre Reinforced Concrete, *Proceedings of the International Symposium on Fibre Reinforced Concrete*, India, 1-18.

Soroushian, P., Tlili, A., Alhozaimy, A., & Khan, A. (1993) Development and Characterization of Hybrid Polypropylene Fibre Reinforced Cement Composites, *ACI Journal*, **90**(2), 182-189.

Yao, W., Li, J., & Wu, K. (2002) Mechanical Properties of Hybrid Fibre-Reinforced Concrete at Low Fibre Volume Fraction, *Cement and Concrete Research*, **33**, 27-30.

You, Z., Chen, X., & Dong, S. (2011) Ductility and Strength of Hybrid Fibre Reinforced Self-Consolidating Concrete Beam with Low Reinforcement Ratios. *Systems Engineering Procedia* **1**, 28-34.