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Pre-peak Flexural Performance Evaluation of Fiber Reinforced Concrete Beams

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Abstract: Flexural behavioural understanding of fiber reinforced concrete necessitate the detailed investigation of load-deflection curve. This study provides additional insight on the solo contribution of fibers on bending properties. This paper aims to understand the pre-peak performance of polypropylene fiber and steel fiber reinforced concrete beams under two-point loading. Polypropylene fiber was used at 0.05% dosage by volume and steel fiber at 0.75%. Reinforced concrete beam specimens of 200mm x 300mm x 2100mm dimension were prepared and tested in simply supported condition. Load-deflection curves plotted and studied for pre-peak energy absorption capacity, gradient angle, load and deflections at yield and peak stages. Experimental results indicated an improvement in energy absorption capacity of steel fiber reinforced concrete specimens by 63.44%. Gradient angle became steeper for polypropylene and steel fiber reinforced specimens. Substantial increase of 52.2kN and 50.1kN were observed for yield and ultimate load values due to steel fiber inclusion in controlled concrete.

Keywords: Bending properties, Gradient angle, PFRC, SFRC,

I. INTRODUCTION

Since 1980 good amount of investigations are carrying out in the area of fiber reinforced concrete. Synthetic, metallic, natural and glass fibers were used in mortar and concrete to improve its properties. The main objective of fiber reinforcement is to reduce the amount of micro cracks, size of crack and control its growth effectively in order to improve the concrete tensile strength [1]. Polypropylene fiber addition distinctly reduces the surface bleeding and the settlement of aggregate in fresh concrete. It is also helpful to control the shrinkage of concrete.Steel fiber in different geometry and aspect ratio is the most used metallic fiber in concrete.It acts as secondary reinforcement used along with conventional rebars as primary reinforcement. The influence of steel fiber on concrete depends on cross section, strength, fiber content, bond strength, shape and length [2].The steel fiber inclusion in concrete proved to be highly beneficial in improving the mechanical properties of concrete. The addition of steel fiber consistently improved the deformation capacity and also change the failure mode from brittle to ductile mode [3] [4]. Volume and aspect ratio of steel fiber greatly influence crack spacings, number of cracks and crack widths in concrete. [5] Smaller crack spacings and greater number of cracks were noticed for SFRC specimens.

Figure 1 indicate the typical load-deflection curve. Pre-peak zone ranges from beginning of loading to till the concrete specimen reaches the ultimate or peak load (P_u). Usually linear curve was observed up to first crack or yield load (P_y). Portion of the curve between first crack and ultimate load was termed as cracked section and good number of cracks appeared in the face of beam specimen. Any improvement due to fiber can be evidenced in cracked section in form of more number of cracks, reduced crack width and increase in the load.

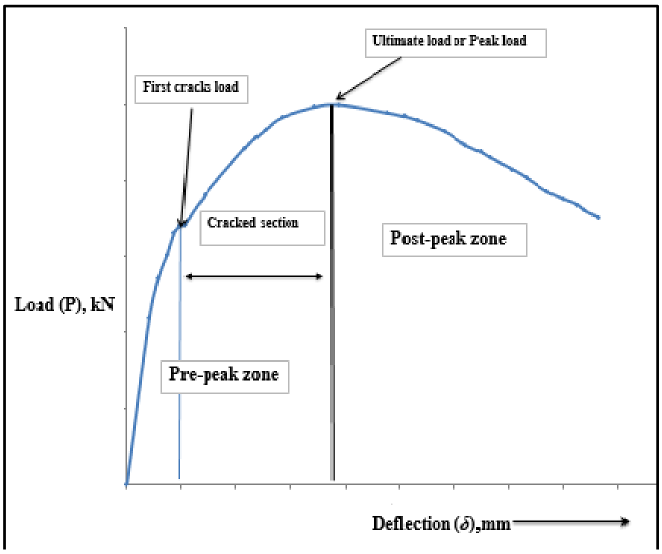

Fig 1 Typical load deflection curve

Different testing conditions and methods were used to understand the influences of fiber on the flexural behaviour. Basically ASTM 1018 and JSCE SF-4 were followed to evaluate the flexural behaviour of fiber reinforced concrete. Flexural toughness in JSCE approach provided a [6] simple technique which exhibited good correlation with fiber reinforcing matrix. Four-point loading flexural test on prism specimens were conducted as per the guidelines of ASTM C1609 to assess the flexural toughness

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indices, flexural strength and residual strength factors [1] [7]. An improved method consists [8] of analysing the load-deflection curve and calculation of post-crack strength (PCS_m) in the post peak region at various deflections exhibited good information about the fiber geometry and matrix strength.

Prism specimens of dimension 100 x 100 x 400 mm with 30 mm notch (0.3 times the height of prism) were tested to record the crack mouth opening displacement (CMOD) and load in three-point bending test [9]. The bending tests were performed on 150 x 150 x 600 mm prismatic specimens to record the peak load, CMOD and crack tip opening displacement (CTOD) as per the EN 14651 (three-point bending) and UNI 11039-2 (four-point bending) with introduced crack of depth 25mm at mid span [10].The studies were conducted on the prismatic reinforced concrete beams made with polypropylene fibers [11], steel fiber [12] [13] [14] and hybrid fiber [15] to understand the flexural behaviours.[16] Reinforced concrete beams of dimension 200 x 300 x 3000 mm were tested under two monotonically applied load in simply supported end condition to understand the flexural strength andductility as function of stress strain response, ductility factor and load-deflection response.

Noticeable experimental works were carried in past to characterize the flexural behaviour of fiber reinforced concrete (FRC). The bending behaviours of FRC were studied in terms of CMOD and CTOD of unreinforced concrete prism. Load-deflection behaviour, ductility, flexural toughness factor and crack pattern were observed on reinforced prismatic beams with mono and hybrid fibers. This present study provides more insight about the performance improvement experienced due the presence randomly distributed mono polypropylene and steel fibers in reinforced concrete (RC) beams. The pre-peak region of load-deflection curves was studied to understand the enhancement in first crack load (P_y), peak load (P_u), energy absorption capacity (E_{pre}) and deflections (δ) dueto the inclusion of fibers.

II. MATERIALS AND METHODOLGY

A. Materials

Binder content consist of ordinary Portland cement (OPC) of 53 grade affirming to the recommendation of IS:12269 [17] and micro silica with SiO_2 content 90.5%. Twosize classes of coarse aggregates designated as 12.5mm - 4.75mm and 20mm - 4.75 mm conform to single size class of IS 383 [18] along with manufactured sand confirming to Zone II of IS: 383 [18] and IS:2386 part I and III [19] [20] with fineness modulus 2.98, specific gravity 2.62 and water absorption 1.20% were used as aggregate in the experimental work. Polycarboxylic ether based superplasticizer was used to maintain the high workability as per IS 456 [21].Monofilament polypropylene fiber with cut length 12mm and aspect ratio 300, density 946 kg/m^3 and specific gravity 1.36, was incorporated to controlled concrete at 0.05% by volume.

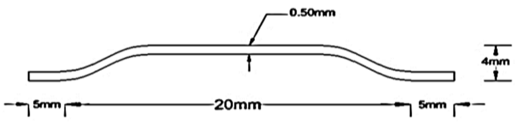

Fig. 2 Geometry of steel fiber

Hooked-end steel fiber having geometry depicted in figure 2, with diameter 0.50mm and tensile strength of 1345 N/mm^2 was used as metallic fiber. 0.75% by volume dosage was considered in SFRC specimen.

B. Test Methodology

A comprehensive mix design based on the packing density approach was adopted [22]to design 60 N/mm^2 controlled concrete. The mix design details are tabulated in table 1.

Table 1 Mix details of FRC

Materials	Quantity
OPC, kg/m^3	325.35
Micro silica, kg/m^3	81.23
Coarse aggregate, kg/m^3	
20mm – 4.75mm	739.25
12.5mm – 4.75mm	492.83
Fine aggregate, kg/m^3	821.39
Superplasticizer, kg/m^3	4.87
Polypropylene fiber, kg/m^3	1.30
Steel fiber, kg/m^3	19.52
Water, kg/m^3	138.27

Three RC beam specimens of dimension 200mm x 300mm x 2100mm were prepared for both polypropylenefiber reinforced concrete (FRC) and steel fiber reinforced concrete (SFRC). Under reinforced RC beam specimen was designed as per the limit state method of IS 456 [21] with reinforcement details as shown in figure 3.

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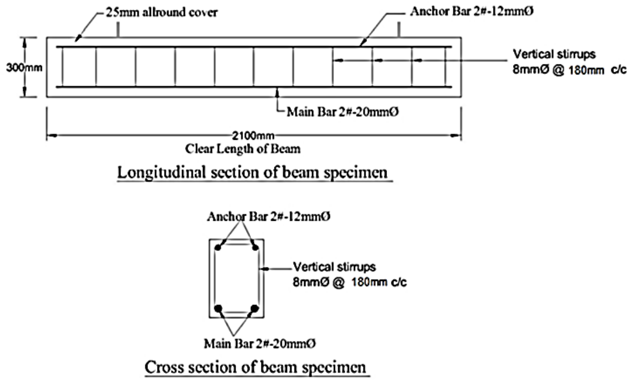

Fig.3 Reinforcement details of RC beam specimen

Specimens were moist cured for 28 days before testing under two-point loading with simply supported end conditions in a loading frame of 1000kN capacity. Eight channel data logger and linear variable transducer (LVDT) of accuracy 1/100th mm were utilized to continuously record the load and corresponding deflection values. The loading was halted at 70% of peak load. Load- deflection curves were plotted and the observations of pre-peak zone of controlled concrete (CC), PFRC and SFRC were compared to comprehend the fiber influence. Yield load (P_y), ultimate load (P_u), yield deflection (δ_y), ultimate deflection (δ_u), gradient angle (θ), pre-peak energy absorption capacity (E_{pre}) were analysed.

III. RESULTS AND DISCUSSIONS

The gradient angle 'θ' is the slope of the load-deflection curve in pre-peak region up to first crack load. Pre-peak energy absorption capacity of CC, PFRC and SFRC are the area under load-deflection curve up to ultimate load.

Results of two-point bending test on CC, PFRC and SFRC RC beam specimens are tabulated in table 2. It was observed from figure 4-6 the curvature of load-deflection curves up to yield point showedmore linearity with inclusion of fibers. The 'θ' value increase to 84.67 with inclusion of 0.05% of polypropylene fiber. SFRC indicated increase in linearity by 4.62 % and 2.69 % compared to CC and PFRC. Increase in linearity was the result of crack bridging and strain hardening [9] effect imparted by randomly distributed polypropylene and steel fiber. Higher tensile strength of steel fiber than polypropylene fiber resulted in boosted gradient in pre-crack section.

Pre-peak energy of the SFRC specimens witnessed considerable increase. Inclusion of polypropylene fiber improve the E_{pre} value of CC specimens by 398.34 kN-mm. This performance of FRC clearly indicated better stress distribution within the concrete matrix due to the presence of randomly distributed fibers. The CC specimens displayed minimum P_y value of 58.4 kN and this value was increase up to 110.6 kN for SFRC. Hooked-end of steel fiber ensures better bonding, which resulted in 56.87 % more yield load compare to PFRC [23] [24]. On theother hand, SFRC beam specimens displayed an enhancement of 33.53% in P_u value compared to CC specimens. This improvement was due to bridging effect of fibers and matrix properties [12] [9]

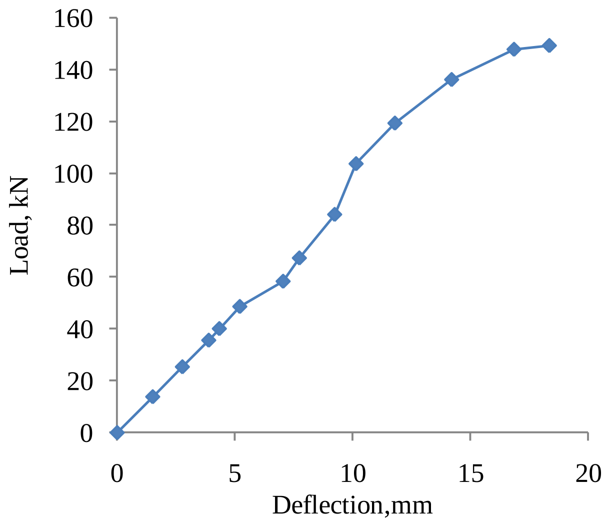

Fig. 4 Normalised pre-peak load-deflection curve of CC specimen

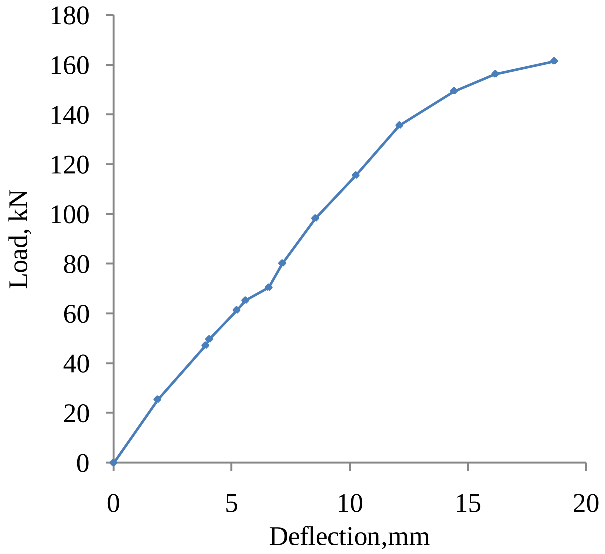

Fig. 5 Normalised pre-peak load-deflection curve of PFRC specimen

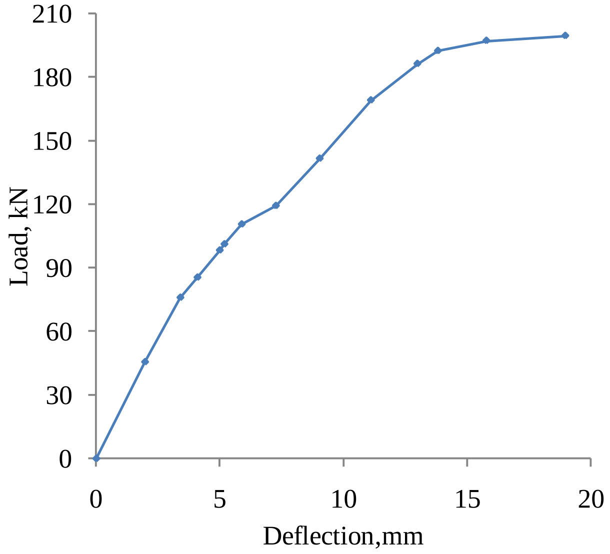

Fig.6 Normalised pre-peak load-deflection curve of SFRC specimen

Table 2 Normalised pre-peak load-deflection response of RC beam specimens

Mix code	P_y, kN	δ_y, mm	P_u, kN	δ_u, mm	θ	E_{pre}, kN-mm
CC	58.4	7.05	149.4	18.36	83.11	1905.02
PFRC	70.5	6.57	161.5	18.65	84.67	2303.36
SFRC	110.6	5.88	199.5	18.96	86.95	3113.72

Deflection values of FRC showed reduction compared to CC specimens. Steady reduction of δ_y value observed in PFRC and SFRC. Overall reduction of 19.89 % in δ_y indicated FRCs resistance for strength decay.The $\delta_u$values of PFRC and SFRC exhibited negligible increase of 1.57 % and 3.26% which was associated with noticeable P_u values increase.

IV. CONCLUSION

Flexural behaviours of concrete beam specimens were studied only in the pre-peak region of load-deflection curve to understand the contribution of mono fibers in early stage of loading. Conclusions arrived based on the experimental results were enlisted.

- Gradient angle indicated the resistance of concrete matrix to deflect and additional contributions of polypropylene and steel fiber. Steeper gradients of FRCs indicated the fiber bridging mechanism in concrete matrix.
- SFRC displayed more pre-peak strain energy among all specimens. ItsE_{pre} value was substantially higher compared to PFRC and CC. Due to early rupture and low tensile strength of polypropylene fiber, PFRC showed lesser value. But it bettered E_{pre} value of CC specimens.
- Yield and ultimate load values were improved due to fiber in controlled concrete matrix. This specified the fiber resistance to deflect and strength decay.

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REFERENCES

[1] YAO Wu, Flexural strength and beahvior of polypropylene fiber reinforced concrete beams, Journal do Wuhan University of Technology -Mater.Sci.Ed, Vol 17, No. 2, June 2002, pp 54-57.

[2] Hamid Pesaran Behbahani, Behzad Nematollahi, Majid Farasatpour, Steel Fiber Reinforced Concrete: A Review, Proceedings of ICSECM 2011, Kandy, Srilanka,

[3] Yoon-Keun Kwak, Marc O.Eberhard, Woo-Suk Kim, Jubum Kim, Shear strength of steel fiber - reinforced concrete beams without stirrups, ACI Structural Journal, Vol 99, No. 4, July - August 2002, pp 530-538.

[4] Jordon R. Deluce, Frank J. Vecchio, Cracking Behavior of Steel Fiber-Reinforced Concrete Members Containing Conventional Reinforcement, ACI Structural Journal, Vol 110, No. 3, May - June 2013, pp 481-490.

[5] Peter H. Bischoff, Tension Stiffening and Cracking of Steel Fiber-Reinforced Concrete, Journal of Materials in Civil Engineering, ASCE, Vol 15, No. 2, April 2003. pp 174-182, doi: 10.1061/(ASCE)0899-1561(2003)15:2/(174).

[6] Nataraja M.C., Dhang N. & Gupta A.P., Toughness characterization of steel fiber-reinforced concrete by JSCE approach, Cement and Concrete Research, Vol 30, 2000, pp 593- 597.

[7] D. V. Soulioti, N. M. Barkoula, A. Paipetis and T. E. Matikas, Effects of Fibre Geometry and Volume Fraction on the Flexural Behaviour of Steel-Fibre Reinforced Concrete, Strain, Vol 47, 2011, e535-e541, doi: 10.1111/j.1475-1305.2009.00652.x.

[8] Jean-Francois Trottier & Nemkumar Banthia, Toughness characterization of steel-fiber reinforced concrete, Journals of Materials in Civil Engineering, Vol 6, 1994, pp 264-289.

[9] D.-Y. Yoo, Y.-S. Yoon, N. Banthia, Flexural response of steel-fiber-reinforced concrete beams: Effects of strength, fiber content, and strain-rate, Cement and Concrete Composites, Vol 64, 2015, pp 84-92, doi: 10.1016/j.cemconcomp.2015.10.001.

[10] Francesco Bencardino, Lidia Rizzuti, Giuseppe Spadea, Ramnath Narayan Swamy, Implications of test methodology on post-cracking and fracture behaviour of Steel Fibre Reinforced Concrete, Composites: Part B, Vol 46, 2013, pp 31–38, http://dx.doi.org/10.1016/j.compositesb.2012.10.016.

[11] Tariq M. Nahhas, Flexural behavior and ductility of reinforced lightweight concrete beams with polypropylene fiber, Journal of Construction Engineering And Management, Vol 1, No. 1, February 2013, pp 4-11.

[12] Fatih Altun, Tefaruk Haktanir, Kamura Ari, Effects of steel fiber addition on mechanical properties of concrete and RC beams, Construction and Building Materials, Vol 21, 2007, pp 654-661, doi:10.1016/j.conbuildmat.2005.12.006.

[13] Qian Chunxiang & Indubhushan Patnaikuni, Properties of high-strength steel fiber-reinforced concrete beams in bending, Cement and Concrete Composites, Vol 21, 1999, pp 73-81.

[14] Halit Cenan Mertol, Eray Baran, Hussain Jibril Bello, Flexural behavior of lightly and heavily reinforced steel fiber concrete beams, Construction and Building Materials, Vol 98, 2015, pp 185–193, http://dx.doi.org/10.1016/j.conbuildmat.2015.08.032.

[15] Yining Ding, Zhiguo You, Said Jalali, Hybrid fiber influence on strength and toughness of RC beams, Composite Structures, Vol 92, 2010, pp 2083–2089, doi:10.1016/j.compstruct.2009.10.016.

[16] Pam, H.J., Kwan, A.K.H., Islam, M.S., Flexural strength and ductility of reinforced normal- and high strength concrete beams, Proceedings of the Institution of Civil Engineers: Structures And Buildings, Vol 146, No.4, 2011, pp 381-389.

[17] IS 12269 (1987) Indian standard, ordinary Portland cement, 53 grade — specification. New Delhi: Bureau of Indian Standards.

[18] IS 383 (1970) Indian standard, specification for coarse and fine aggregates from natural sources for concrete. New Delhi: Bureau of Indian Standards.

[19] IS 2386 part-I. (1963). Indian standard, Methods of test for aggregates for concrete - Particle size and shape. New Delhi: Bureau of Indian Standards.

[20] IS 2386 part-III. (1963). Indian standard, Methods of test for aggregates for concrete - Specific gravity, density, voids, absorption and bulking. New Delhi: Bureau of Indian Standards.

[21] IS 456. (2000). Indian standard, Plain and reinforced concrete - Code of practice. New Delhi: Bureau of Indian Standards.

[22] Shashi Kumara S.R., D.L. Venkatesh Babu, B. C. Udayashankar, Experimental study on optimization of mid strength high performance concrete using particle packing technique, International Journal of Engineering & Technology, Vol. 7, No. 4, 2018, pp. 5272-5280, doi: 10.14419/ijet.v7i4.27589.

[23] Biao Li, Yin Chi, Lihua Xu, Yuchuan Shi, Changning Li, Experimental investigation on the flexural behavior of steel-polypropylene hybrid fiber reinforced concrete, Construction and Building Materials, Vol 191, 2018, pp 80–94, https://doi.org/10.1016/j.conbuildmat.2018.09.202.

[24] G. Pons, M. Mouret, M. Alcantara, J. L. Granju, Mechanical behaviour of self-compacting concrete with hybrid fibre reinforcement, Materials and Structures, Vol 40, 2007, pp 201-210, DOI 10.1617/s11527-006-9131-y.

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