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Behaviour of Polypropylene and Steel Fibre Reinforced High Strength Concrete Exterior Beam Column Joint

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Abstract. The present work aims at studying the performance of polypropylene and steel fibre reinforced high strength concrete in exterior joint of beam-column. Individually and in combination, steel fibre with 0.25 %, 0.50 %, 0.75 %, and 1 % by volume of concrete and polypropylene fibre with 0.16 % and 0.32 % by volume of cement were induced into the concrete. The characteristics investigated are energy absorption capacity, displacement ductility and shear carrying capacity. From the obtained test results, it is concluded that 0.16% polypropylene fibre with 0.75% steel fibre in hybrid fibre composites show desired strength in all aspects of investigation.

Introduction

A critical component in framed structure is a joint in beam-column, which is subjected to compressive force, tensile force and shear force. In general, under loading condition, these joints are expected to withstand high load without any significant loss in deformation. But in nature under cyclic loading, these joints will fail in shear with spalling of concrete in beam column junction and loss of bond between the reinforcement and concrete matrix. To overcome this problem closely spaced stirrups near the joint is the conventional way to avoid the shear failure in the junction, but it leads to congestion of steel reinforcement and it affects the compaction of concrete. [1] concluded that the possible solution to avoid the congestion of steel reinforcement in joint of beam-column is the use of steel fibres in concrete. Addition of metallic and nonmetallic fibres in concrete intense the tensile capacity of concrete by bridging the micro and macro cracks [2]. Similarly [3] reported increase in load carrying capacity and energy dissipation with increased stiffness retention in exterior joint of beam-column for hybrid cementitious composites compared to non fibre reinforced specimen. [4] concluded that random dispersion of fibres inside the concrete provides three-dimensional reinforcing network which improves better diffusion of stresses both internally and externally. Fibres in joint of beam-column in hybrid form increases the first crack load, ultimate load and ductility factor of the composite [5]. However higher percentage of steel fibre more than 1% volume of concrete combined with 0.2% of polypropylene fibre leads concrete to become harsh due to the balling effect of fibres [6].

[7-9] reported that available codes for seismic and non-seismic design inexact the joint shear strength of the non-seismically designed detailed joints. The main objective of this study is to

determine the energy absorption capacity, displacement ductility and shear carrying capacity in exterior joint of beam-column.

Materials and mix proportions

Materials Used

Ordinary Portland Cement, 53 grade, with a specific gravity of 2.97, was employed in this study. According to IS: 4031-Part 4 [10] and IS: 4031- Part 5 [11], the standard consistency of the cement was 34.5% and the initial and final setting time of the cement were 54 and 280 minutes respectively. 5% weight of cement was partially replaced with microsilica to improve the homogenous property of concrete. River sand having specific gravity of 2.66 and fineness modulus of 3.21, and coarse aggregate with a specific gravity of 2.84 and a fineness modulus of 6.68 was graded in a blend of 70% - 12.5mm passing and 10mm retaining and 30% - 10mm passing and retaining on 4.75mm. Polycarboxylic based ether superplasticizer with maximum dosage of 1.5% by weight of cement was used in this study. 20mm length with 0.04mm lateral dimension polypropylene fibre having a tensile strength of 500 N/mm^2 and 35mm length with 0.45mm diameter steel fibre having a tensile strength of 1000 N/mm^2 were used in this study.

Mix Proportion

According to ACI 211.4R-93 [12], a very high strength concrete matrix of M80 grade was achieved. Table 1 presents the concrete mix proportion. Details of mix designation are given in Table 2. In the mix designation, CM stands for control mix, P1 for concrete with 0.16% and P2 for concrete with 0.32% polypropylene fibre; S1 for concrete with 0.25%, S2 for 0.50%, S3 for 0.75% and S4 for 1.00% steel fibre. Initially, powder materials like dry cement were mixed with microsilica and fine aggregate for one minute in a laboratory pan mixer machine; following that, fibres were unevenly scattered to the dry mix and the process was repeated for another two minutes, and then coarse aggregate with 75% volume of water was added and mixed continuously for three minutes. Superplasticizer was dissolved in the remaining 25% volume of water and this mixer was poured into the wet concrete. Once again, it was mixed thoroughly for another 4 to 5 minutes and finally it was poured into the mould. Removal of mould was done after 24 hours and specimens were cured for 28 days testing. Concrete specimens were prepared for all the fibre combinations like P1, P2, S1, S2, S3, S4, P1S1, P1S2, P1S3, P1S4, P2S1, P2S2, P2S3, P2S4 including CM and all the mechanical characteristics like compressive strength, splitting tensile strength and flexural strength were determined. Based on this, only P1, P2, S1, S2, S3, S4 and best performed hybrid combinations P1S3 and P2S3 alone were used in this study.

Table 1 *Mix proportion*

Material	Weight (kg/m^3)
Cement	691.15
Microsilica	36.38
Fine aggregate	657.64
Coarse aggregate	630 (12.5mm passing and 10mm retaining)
	270 (10mm passing and 4.75mm retaining)
Water	189
Superplasticizer	10.9

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Table 2 *Mix designation*

Mix Designation	% of Polypropylene Fibre (V_f)	% of Steel Fibre (V_f)
CM	0	0
P1	0.16	0
P2	0.32	0
S1	0	0.25
S2	0	0.50
S3	0	0.75
S4	0	1
P1S3	0.16	0.75
P2S3	0.32	0.75

V_f - Volume Fraction

Experimental Program

Totally, eighteen exterior joint of beam-column were investigated in this experimental investigation. Each specimen consisted of a beam of 100mm wide and 150mm deep framing in to the column of 100mm x 100mm cross section. All beams were reinforced with a same amount of main reinforcing bar of 2 Nos of 8mm diameter bar at top and bottom sides of the cross section, and column with 4 Nos of 8mm diameter. 6mm diameter bar with 90mm centre to centre spacing were used as stirrups and lateral ties in beam and column respectively. According to IS 13920-1993 [13], the top and bottom reinforcement of beam were bent to 90^0 and anchored to the column with the anchorage length of 50 times of reinforcing bar diameter from the face of the column. Fig. 1 shows joint of beam-column detailing. To investigate the structural behaviour of exterior joint of beam-column, the specimen was placed in a 500 kN loading frame with both ends of the column in fixed condition. The load was applied gradually at a distance of 100mm from the end of beam with an increase of 1 kN and the resulting deflection was observed under the load point. Fig. 2 shows joint of beam-column test set up.

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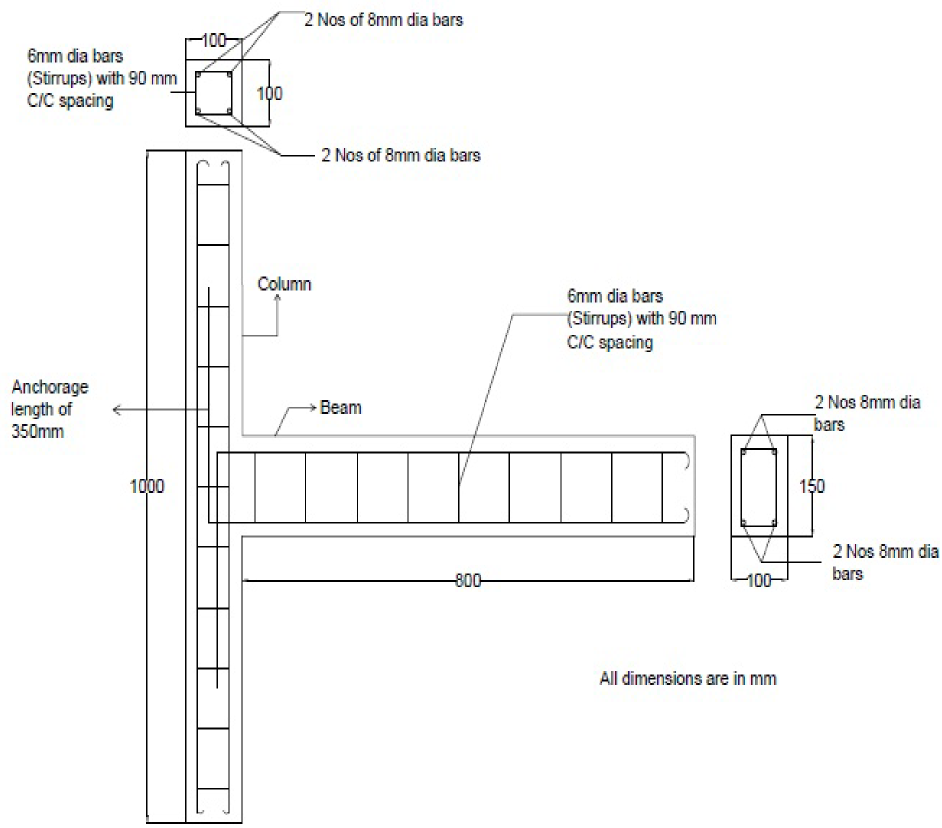

Fig. 1. *Reinforcement detailing of exterior joint of beam-column*

Fig. 2. *Test set up of exterior joint of beam-column*

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Formulae for calculating joint shear force

Joint shear force

The joint shear force in exterior joint of beam-column is calculated according to Kuang. J.S [7], is expressed as Shear force in the joint core $V_j = T - V_{col}$. where T - tensile force in steel of the beam; and V_{col} - shear force of the column. The values of T and V_{col} may be calculated by $T = (P\ l_b / 0.9\ d_b)$ and $V_{col} = [P\ (l_b + 0.5\ h_c) / l_c]$. where P - applied load in the beam in kN; d_b - effective depth of beam in mm; h_c - effective depth of column in mm; l_b & l_c - effective length of beam and column.

Prediction of shear force by ACI 318R-05:2002

As per ACI 318R-05:2002 [14], the joint shear force in the exterior joint of beam-column calculated by $V_n = 0.85\ \gamma \sqrt{(f_c')}A_j$. where f_c' is compressive strength of cylinder in N/mm^2 ($f_c' = 0.8\ f_{cu}$) while designing the joint of beam-column; A_j - joint of beam-column effective area in mm^2 (100mm x 100mm); and γ is a coefficient based on type of joint in beam-column. The values of γ are $\gamma = 1.0$ for corner joint, $\gamma = 1.25$ for exterior joint and $\gamma = 1.67$ for interior joint. In this study, the specimen is classified as exterior joint. While calculating the ultimate shear capacity in the joint of beam-column, the factor of safety is not taken in to account and the equation can be rewritten as $V_n = 1.25 \sqrt{(f_c')}A_j$.

Prediction of shear force by NZS 3101: 1995

From NZS 3101:1995 [15], the joint shear force in the exterior joint of beam-column for seismic design code was calculated using the formula $V_n = 0.2\ f_c' A_j$. where f_c' is cylindrical specimen compressive strength in N/mm^2 ($f_c' = 0.8\ f_{cu}$); A_j - joint of beam-column effective area in mm^2.

Experimental results and discussions

Failure mode of test specimens

Fig. 3 to Fig. 6 show the failure pattern of exterior joint of beam-column concrete specimens. All the specimen developed tensile crack at the interface between column and beam. Similar to Ganesan. N et al. [5], a clear vertical cleavage was formed at the junction of all the specimens. From the observation, it was clearly noted that polypropylene fibre arrested the formation of micro cracks under load in initial stage and steel fibre arrested both micro and macro cracks under load in initial and ultimate stage. The first crack load increased by 6.48% for P1 and 4.16% for P2 specimens. Similarly for steel fibre based mix, except S2 mix all specimens showed increase in first crack load by 11.11% for S1, 27.31% for S3 and 38.88% for S4 specimens compared to control mix. It was discovered that while adding hybrid fibres to a hybrid fibre mix does not raise the first crack load, it does resist a larger peak load in the ultimate stage in comparison to the control specimen. For specimen P1S3, the crack width is less compared to all other specimen and it withstands higher peak load with large deflection the joint stayed unscathed during the test with minor crack and it is shown in Fig. 6.

***Fig. 3.** Cracks in CM Specimen*

***Fig. 4.** Cracks in P1 Specimen*

***Fig. 5.** Cracks in S3Specimen*

***Fig. 6.** Cracks in P1S3 Specimen*

Load deflection behavior

The yield point load and the ultimate point load of all the concrete specimens are given in Table 3. The curve of load deflection of each specimen with and without fibres is shown in Fig. 7 to Fig. 9. It is perceived from the results that there is considerable improvement in load carrying capability after the induction of fibres Siva Chidambaram. R et al. [3]. P1 and P2 specimen showed 3.84% and 5.76% increase in load carrying capacity and ultimate deflection is more than 1.5 times compared to the control mix. Steel fibre based mix shows increase in load carrying capacity in the range of 34.61%, 42.30%, 68.26% and 80.76% respectively for S1, S2, S3 and S4 compared to the control mix. In hybrid fibre mix, P1S3 shows higher ultimate crack load of 25.4 kN with larger deflection of 43.05mm compared to all other mix, this was attributed to polypropylene fiber's capacity to resist micro fractures from forming and steel fibre to resist macro fractures Vahid Afroughsabet et al. and Ganesan. N et al. [2&5].

Table 3
Experimental results of joint in beam-column

Mix Designation	Compressive strength of companion cubes N/mm^2 (f_{cu})	Yield load and corresponding deflection		Ultimate load and corresponding deflection		Energy absorption capacity kNm	Displacement ductility $\mu = \delta_u / \delta_y$
		Load kN	Deflection mm (δ_y)	Load kN (P_u)	Deflection mm (δ_u)		
CM	80.21	4.32	3.29	10.4	16.22	0.055	4.93
P1	80.49	4.6	4.3	10.8	30.6	0.056	7.12
P2	80.44	4.5	4.53	11	24.75	0.053	5.46
S1	81.04	4.8	4.22	14	29.72	0.083	7.04
S2	83.44	4	3.6	14.8	30.22	0.106	8.39
S3	85.63	5.5	4.81	17.5	33.64	0.133	6.99
S4	85.78	6	3.36	18.8	36.83	0.182	10.96
P1S3	85.16	4	3.23	25.4	43.05	0.342	13.33
P2S3	85.97	3.5	2.5	16	30.26	0.176	12.10

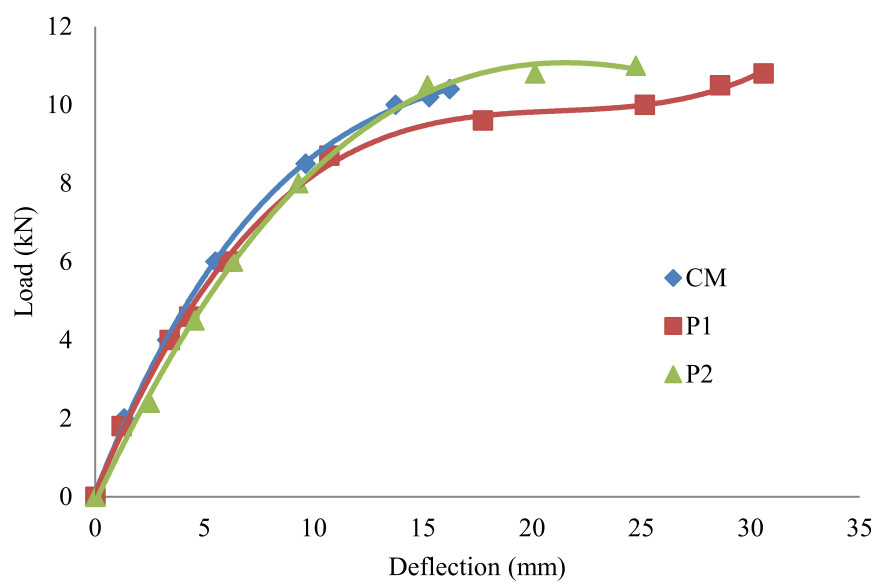

***Fig. 7.** Load deflection curves of beams with control mix and polypropylene fibre mix*

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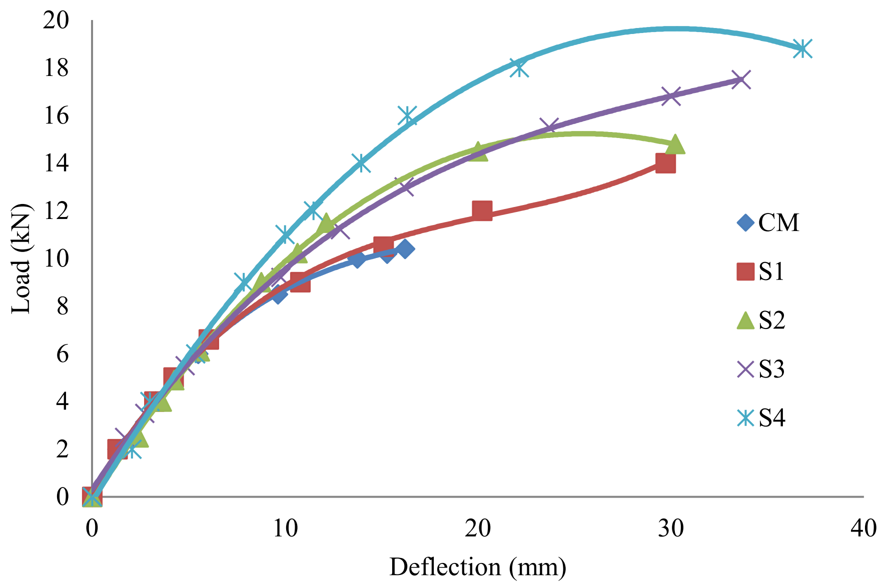

***Fig. 8.** Load deflection curves of beams with control mix and steel fibre mix*

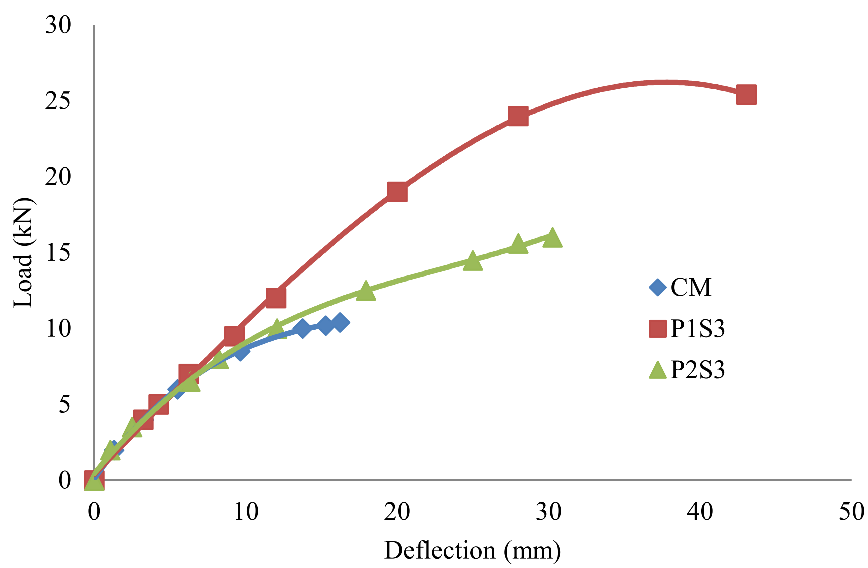

***Fig. 9.** Load deflection curves of beams with control mix and hybrid fibre mix*

Energy absorption capacity and displacement ductility

To measure energy absorption capacity, the area beneath the load deflection curve was computed, and the findings are shown in Table 3. From the test results, it is clearly noticed that addition of fibres increases the energy absorption capacity consistently and it reaches a maximum for P1S3 mix, which is around 6.2 times greater than control mix. Displacement ductility refers to the ductility of a structure or an element and it is defined as the ratio of ultimate deflection to yield deflection. Table 3 shows the displacement ductility for all mix. It is observed that P1S3 mix showed increase in displacement ductility value of 170.38% compared to all other mix.

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Joint shear force

The joint shear force values obtained through the experiments are shown in Table 4. It is clear that adding fibres to concrete increases the joint shear force. P1 and P2 mix shows 3.83% and 5.75% increase in joint shear force compared to control mix. For steel fibre based mix, S4 showed 80.75% increase in strength. In high peak load, it exhibits steel fibres suppressing the growth of micro cracks and bridging larger cracks. This directly increases the ductility behavior at joint of beam-column. In hybrid fibre mix, P1S3 shows 144.22% increase in joint shear force compared to the control mix. The increase in shear force with addition of fibres is due to the formation of strong interface zone between the fibres and the concrete matrix.

Table 4

Experimental and theoretical joint shear force

Mix designation	Joint shear force kN	Joint shear force kN		V_{exp}/V_{ACI}	V_{exp}/V_{NZS}
		ACI 318R-05:2002	NZS 3101:1995		
CM	62.55	100.13	128.34	0.62	0.49
P1	64.95	100.31	128.78	0.65	0.50
P2	66.15	100.27	128.70	0.66	0.51
S1	84.20	100.65	129.66	0.84	0.65
S2	89.01	102.13	133.50	0.87	0.67
S3	105.25	103.46	137.01	1.02	0.77
S4	113.06	103.55	137.25	1.09	0.82
P1S3	152.76	103.17	136.26	1.48	1.12
P2S3	96.22	103.66	137.55	0.93	0.70

Comparison with design codes

The joint shear force calculated from the experimental data in the exterior joint of the beam-column was compared to existing seismic codes of design ACI 318R-05:2002 and NZS 3101:1995 (Table 4). As illustrated in Fig. 10, both the ACI and NZS codes overestimate the joint shear force. Experimental results obtained were lesser by 50% than the predicted values by these two codes for the control mix, P1 and P2 mix and thus the obtained results are coinciding with the results obtained by Kuang. J.S et al. [7]. According to ACI 318R-05:2002 code, for steel fibre based mix, except S3 and S4 mix the specimens showed increase in predicted values of 19.54% for S1 and 14.71% for S2 mix respectively. Similarly, for NZS 3101:1995 code, S1 and S2 mix showed increase in predicted values by 54% and 49.99%. In hybrid fibre mix, the predicted values from both codes showed decrease in value by 32.45% and 10.80% for P1S3 mix. Therefore, it is found that ACI and NZS codes for predicting joint shear in joint of beam-column the concrete without fibres was overestimated, while the hybrid fibre reinforced concrete was underestimated.

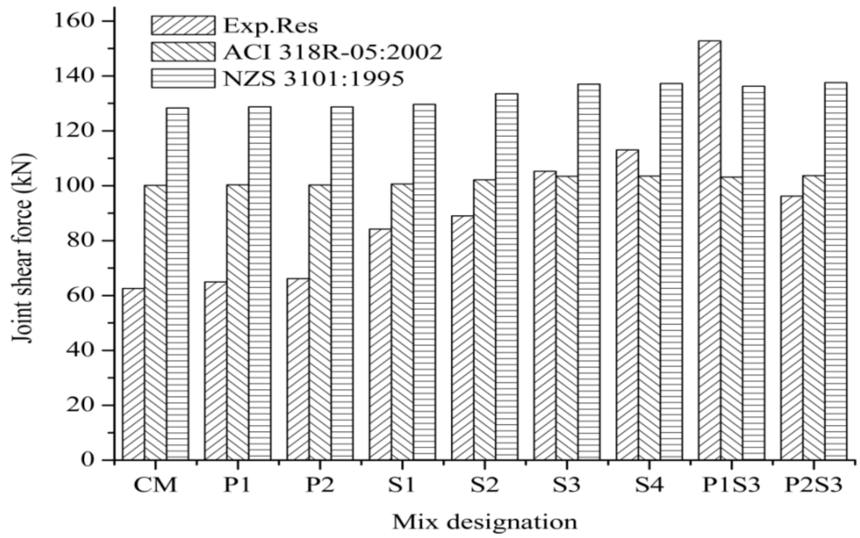

Fig. 10. *Theoretical and experimental comparisons of joint shear force with codes*

Conclusions

The impacts of polypropylene and steel fibre reinforced concrete in the joint of an exterior beam column were analyzed experimentally and numerically in this paper. The following conclusions are drawn from this study.

(1) The test specimen P1S3 (0.16 % polypropylene fibre with 0.75 % steel fibre) has a relatively small crack width than the other specimens, and it can withstand a higher peak load of 25.4 kN and a larger deflection of 43.05mm than the control mix, which can only withstand a peak load of 10.4 kN and a deflection of 16.22mm.

(2) The addition of fibres enhances the energy absorption capacity in the exterior joint of beam-column, reaching a maximum of 6.2 times that of the control mix for P1S3 (0.16 % polypropylene fibre with 0.75 % steel fibre). Similarly, P1S3 (0.16% polypropylene fibre with 0.75% steel fibre) mix shows increase in displacement ductility value of 170.38% compared to control mix.

(3) The increase in joint shear force with addition of fibres is due to the formation of strong interface zone between the fibres and the concrete matrix. In this P1S3 (0.16% polypropylene fibre with 0.75% steel fibre) mix shows 144.22% increase in joint shear force compared to the control mix.

(4) Seismic design codes ACI 318R-05:2002 and NZS 3101:1995 for predicting joint shear in joint of beam-column over estimates for the concrete without fibres and under estimates for the hybrid fibre reinforced concrete.

References

[1] C. Röhm, B. Novák, S. Sasmal, R. Karusala, V. Srinivas, Behaviour of fibre reinforced beam- column sub-assemblages under reversed cyclic loading, Construction and Building Materials. 36 (2012) 319-29. https://doi.org/10.1016/j.conbuildmat.2012.04.114

[2] Vahid Afroughsabet, Togay Ozbakkaloglu, Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers, Construction and Building Materials. 94 (2015) 73-82. https://doi.org/10.1016/j.conbuildmat.2015.06.051

[3] R. Siva Chidambaram, Pankaj Agarwal, Seismic behavior of hybrid fiber reinforced cementitious composite beam column joints, Materials and Design. 86 (2015) 771-781. https://doi.org/10.1016/j.matdes.2015.07.164

[4] V. Ramakrishnan, Structural synthetic fibres for three-dimensional reinforcement of concrete, ACI Special Publication. 261 (2009) 55-72.

[5] N. Ganesan, P.V. Indira, M.V. Sabeena, Behaviour of hybrid fibre reinforced concrete beam column joints under reverse cyclic loads, Materials and Design. 54 (2014) 686-693. https://doi.org/10.1016/j.matdes.2013.08.076

[6] N. Ganesan, P.V. Indira, M.V. Sabeena, Bond stress slip response of bars embedded in hybrid fibre reinforced high performance concrete, Construction and Building Materials. 50(2014) 108-115. https://doi.org/10.1016/j.conbuildmat.2013.09.032

[7] J.S. Kuang, H.F. Wong, Effects of beam bar anchorage on beam column joint behavior, Structures & Buildings. 159(2006) 115-124. https://doi.org/10.1680/stbu.2006.159.2.115

[8] J.S. Kuang, H.F. Wong, Effects of beam column depth ratio on joint seismic behavior, Structures & Buildings. 161(2008) 91-101. https://doi.org/10.1680/stbu.2008.161.2.91

[9] S.R. Uma, Sudhir K. Jain, Seismic design of beam column joints in RC moment resisting frames - review of codes, Structural Engineering and Mechanics. 23(2006) 579-597. https://doi.org/10.12989/sem.2006.23.5.579

[10] Indian Standard Method, Physical tests for hydraulic cement, determination of consistency of standard cement paste. IS 4031; Part 4: 1988.

[11] Indian Standard Method, Physical tests for hydraulic cement, determination of initial and final setting times. IS 4031; Part 5: 1988.

[12] American Concrete Institute, Guide for selecting proportions for high-strength concrete with portland cement and fly ash. ACI committee 211: Reapproved 1998.

[13] Indian Standard, Ductile detailing of reinforced concrete structures subjected to seismic forces - code of practice. IS 13920:1993.

[14] American Concrete Institute. Building code requirements for reinforced concrete and commentary. ACI 318 R-05:2002.

[15] Standards Association of New Zealand. The Design of Concrete Structures. NZS 3101:1995.