ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 17, NO. 6(2016)
PAGES 701-712

EFFECTS OF HYBRID FIBER REINFORCED HIGH- STRENGTH CONCRETE IN EXTERIOR BEAM – COLUMN JOINT SPECIMENS

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Received: 20 October 2015; **Accepted:** 10 January 2016

ABSTRACT

This paper investigated the effects of hybrid fiber reinforced high-strength concrete in Exterior beam –column joint specimens. One specimen detailed as per IS 13920, second specimen detailed as per IS 456 code provisions, this two specimens were cast with high strength concrete of Grade M60 and treated as control specimens. Six specimens detailed as per IS 456 but the top & bottom bars of beam were bent-up within the joint core, and maintained the uniform spacing of stirrups for column and beam, those specimens were cast by using the steel fibers, polyolefin fibers were added into the same grade of concrete with various volume fractions. All the specimens were tested by cyclic load, from this test ultimate load, Load deflection behavior, deflection ductility, stiffness were studied and compared the results with control specimens. The hybrid fiber reinforced high strength concrete specimens were gave better performances.

Keywords: High strength concrete; beam – column joints; hybrid fiber; strength; ductility.

1. INTRODUCTION

Beam- column joints in reinforced concrete moment resisting frames are essential region that control the effective distribution of forces in the structure. For this reason, they must be provided with sufficient stiffness, strength and ductility to sustain the loads [1]. To achieve sufficient ductility of beam- column joints, ACI –ASCE committee 352 and IS 13920 have been recommended the use of closely spaced transverse hoop reinforcement. Due to the congestion of reinforcement, casting of beam column joint will get more complicated and it will lead honeycombing of concrete [2]. Therefore the performance of beam column joint

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has been a research topic for several years. Murty et al. [3] have investigated the exterior beam - column joint subjected to cyclic loading by changing the anchorage detailing of main reinforcement and hoop reinforcement. The author was observed that the joint detailing using hairpin type reinforcement is the alternative to the hoop reinforcement in the joint region. Bindhu et al. [4] have made investigations in exterior beam column joints with different joint detailing and validated with analytical study using Finite element software, and concluded that the additional cross bracing reinforcement improves the Seismic performance of the exterior reinforced concrete beam-column joints. Rajagopal et al. [5] have done the experimental investigation of exterior beam column joints designed with different code provisions using three types of joint reinforcement (cross bar, Hair clip, and Shear link) used in the joint core, and concluded that combination of anchorage and joint details may be used in higher ductility demanding situations. Filiatrault et al. [6] have Investigated full - scale exterior beam – column joints with and without seismic detailing and addition steel fiber in the joint core. Experimental results indicated that fiber reinforced concrete is an alternative to conventional confining reinforcement. Some researchers [7-9] studied the effects fiber used as reinforcement in the beam-column joints. They have shown that addition of fibers enhanced the ductility and strength of the beam column joints. Fibers have been used in concrete structures to enhance tensile characteristics by reducing crack growth and improving mechanical behavior. The engineering properties and economic advantages of high-strength concrete (HSC) are different from conventional concrete, thereby popularizing the HSC applications in the construction industry [10]. HSC offers numerous advantages like more strength and durability but it is characterized by high brittleness in the post-peak response. To reduce this effect and to ensure adequate local ductility of the members, a strategy is to add discrete steel fibers as reinforcement in HSC [11]. It has been shown in the previous report that by using the concept of hybridization with two different fibers composite can produce more attractive engineering properties because of one fiber enables the more efficient utilization of the possible properties of the other fiber [12]. In this experimental study one specimen detailed as per IS 13920-1993, second specimen detailed as per IS 456-2000 code provisions, this two specimens were cast with high strength concrete of Grade M60 and treated as control specimens. Six specimens detailed as per IS 456 but the top & bottom bars of beam were bent-up within the joint core. The steel fibers, polyolefin fibers were added into the same grade of concrete for casting the above six specimens with various volume fractions. The prepared specimens were tested by cyclic load and the results were compared.

2. EXPERIMENTAL PROGRAM

2.1 Materials used

Ordinary Portland cement of 53 grade confirming to IS 12269- 1987 was used. The specific gravity of fine aggregate was 2.40. Crushed stone with size of 10 mm coarse aggregate of specific gravity was 2.74 and densified silica fume (D920) obtained from Elkem materials for improving the concrete properties in fresh and hardened states. High-range water reducing admixture Gelenium B233 was used to maintain the workability of concrete. The fibers used in the study were hooked end steel, and Polyolefin straight fibers as shown in Fig. 1. Their properties were given by the manufacturers as shown in Table 1.

(a) Hooked end steel fiber (b) Polyolefin straight fiber

Figure 1. Fibers used for this experimental work

Table 1: Properties of fibers

Fiber Properties	Fiber Details	
	Polyolefin	Steel
Length (mm)	54	35
Shape	Straight	Hooked ends
Size / Diameter (mm)	1.38x0.41	0.6
Aspect Ratio	63.68	58.33
Density (kg/m^3)	920	7800
Specific Gravity	0.90 - 0.92	7.80
Young’s Modulus (GPa)	10	210
Tensile Strength (MPa)	640	>1100

2.2 Design and casting of specimens

The overall dimensions and the details of the reinforcement of the beam –column joints are given in Fig. 2. First specimen (Specimen 1) is designed with seismic detailing as per IS 13920 [13]. Second specimen (Specimen 2) was designed as per IS 456, remaining six specimens were designed without Seismic detailing (specimen 3, No Hoop reinforcement, No confinement at the joint core, the top and bottom beam reinforcements were bent up within the joint core). For all Beam-column joint specimens casting work, the Form work mould was made by using 12 mm water proof centering plywood, the waste oil was applied inside face of the Form work mould to prevent the absorption of water from concrete, and to facilitate easy removal of the specimen, the fabricated reinforcement cage was placed in the mould with proper cover as shown in Fig. 3. In the present investigation seven exterior beam-column joints were considered, Specimen 1 and Specimen 2 were cast with High strength concrete of grade M60, the mix proportions are shown in Table 2 was carried out based on ACI -211-4R-93 [14]. Specimen 3 detailing was utilized to cast with same grade of concrete with addition of steel and polyolefin fibers in terms of volume fractions, the specimen names and their details are shown in Table 3. The mixes were poured into moulds in layers with proper compaction using Needle vibrator, After 24 hours, specimens were demoulded and cured under wet gunny bags for 28 days as shown in Fig. 4.

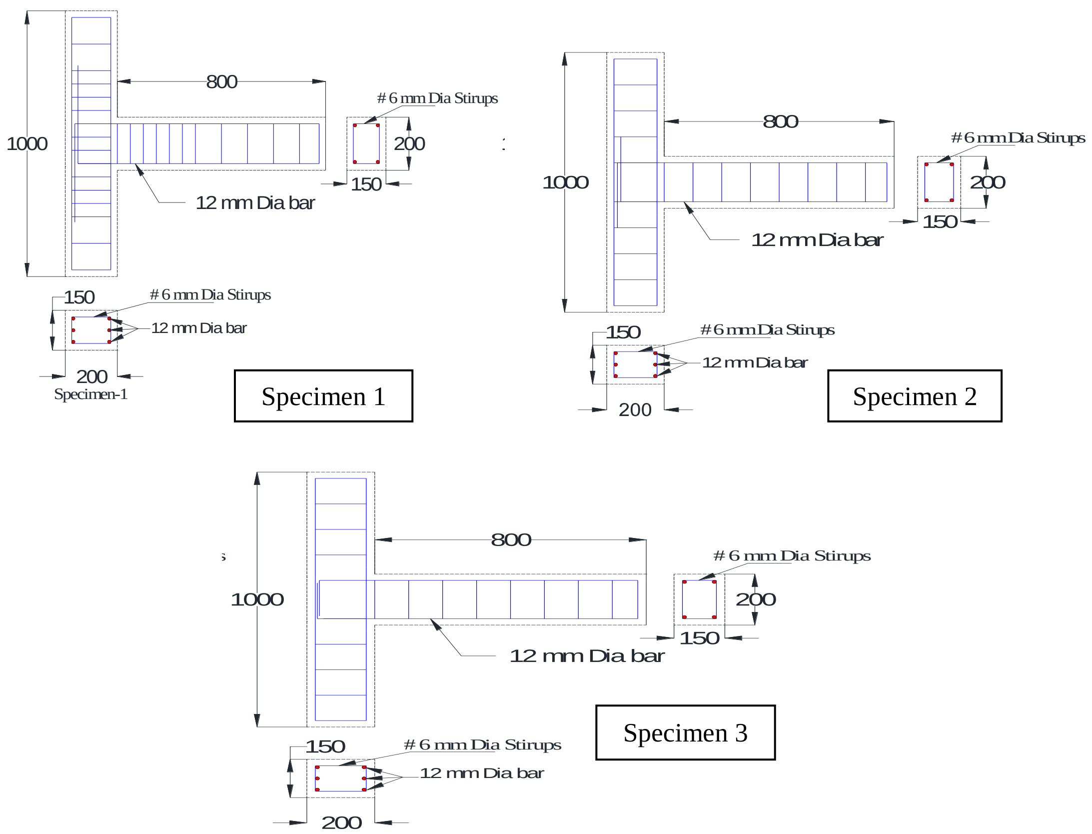


Figure 2. Detailing of exterior beam-column joints

Table 2: Concrete mix proportions for 1m^3 concrete

Materials	Quantity in kg
Cement	468.48
Silica Fume	43.52
Fine Aggregate	594.40
Coarse Aggregate	1037.22
HRWR	6.40
Water	159.50

Table 3: Details of specimens

Sl. No.	Specimen name	Volume fractions (%)		
		Steel	Polyolefin	Total
1	HSBC1	0	0	0
2	HSBC2	0	0	0
2	HSFBC1	1	0	1
3	HYFBC1.1	0.8	0.2	1
4	HYFBC1.2	0.6	0.4	1
5	HSFBC2	2	0	2
6	HYFBC2.1	1.6	0.4	2
7	HYFBC2.2	1.2	0.8	2

Figure 3. Steel cage placed inside the form work with proper cover

Figure 4. Gunny bag curing of specimens

2.3 Test procedure

The specimens were tested 500kN loading frame in a Structural Engineering Laboratory. The column was simulated as hinged-hinged column and applied constant load for keeping specimens in a position. The transverse loading was applied using 500 kN hydraulic jack at 50 mm from the end of the beam. The 50 kN load cell with Indicator was used to measure the applied load accurately. A dial gauges were used to measure the deflections at beam end, middle, and column middle portion. The schematic diagram of test set- up is shown in Fig. 5. The forward cyclic load [15, 16] was applied up to failure of the specimens; the deformations were measured in each stage of loading and unloading with specified load intervals.

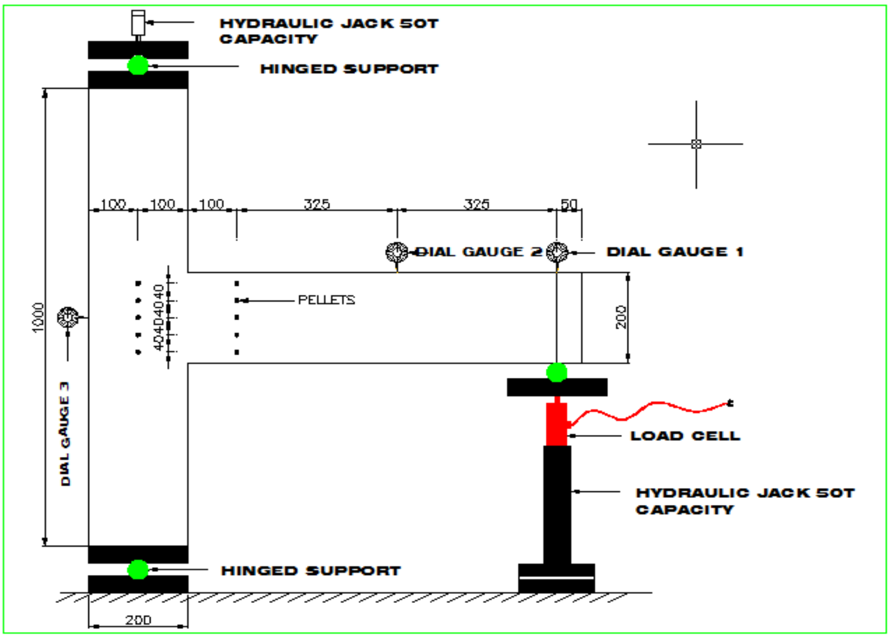


Figure 5. Schematic load set-ups

3. RESULTS AND DISCUSSIONS

3.1 Ultimate load and deflections

The test results of ultimate load and deflection are given in Table 4. It shows that the addition of fibers into the concrete increased the load carrying capacity and deflection at ultimate load. HSBC1 and HSBC2 specimens' ultimate load is 24 kN the same value was obtained for the Hybrid fiber reinforced high strength concrete specimen – HYFBC2.1. The graphs are shown in Fig. 6. When the beam is subjected to cyclic loading, the graphs are shown in Fig. 7. The energy absorption capacity was calculated as the area under the hysteresis loop of the load deflection diagrams. The cumulative energy absorption capacity of the beam-column joint was obtained by adding the energy absorption capacity of the joint during each cycle considered. In this study total energy absorption capacity was calculated from the each cycle Peak load verses deflection curve. The energy absorption capacity and deflection ductility of all specimens are shown in Table 4.The energy absorption capacity was 208.62kN-mm for the control (HSBC1) specimen. The energy absorption capacity of hybrid fiber reinforced high strength concrete non-seismic detailing specimens increased with increase in fiber volume fractions. HYBC2.1 specimen - energy absorption capacity was 257.96kN-mm. It was 23.65 percent more than the energy absorption capacity of HSBC1 specimen. The term Ductility [17] is defined as the ability of structure to undergo large amount of deformations without reduction of its strength. Deflection ductility was calculated by using peak load deflection curves. Deflection ductility of hybrid fiber reinforced high strength concrete specimen HYBC2.1 is more than the control specimen.

3.2 Stiffness

In the case of beam – column joints, stiffness of the joint gets reduced when the joint is subjected to cyclic loading Stiffness is defined as force required to cause unit deflection. The stiffness was calculated, peak load of each cycle divided by the corresponding deflection, the values were plotted as graph as shown in Fig. 8. It shows the gradation of stiffness of all specimens. Initial stiffness were calculated - ultimate load divided by the deflection at yield, the values are shown in Table 4. Initial Stiffness of hybrid fiber reinforced high strength concrete specimens is very nearer to control specimens.

3.3 Crack pattern

All the specimens were initiated the crack at beam column junction after the first crack load, further increase of load the cracks started to widen and developed in upward direction of beam. Small minor cracks can be visible in the control specimens but that is not available in the fiber and hybrid fiber reinforced high strength concrete specimens. The width of the crack of fiber and hybrid fiber reinforced high strength concrete specimens was very less compared with that of control specimens. It may be understand that the fibers are bridging the formation of minor cracks. Crack pattern of specimens after failure is as shown in Fig. 9.

Table 4: Test results of ultimate load deflection ductility and stiffness

Specimen Name	**First Crack Load kN**	**Deflections at Yield $\delta_{y(mm)}$**	**Ultimate Load P_u (kN)**	**Ultimate Deflection δ_u (mm)**	**Deflection Ductility δ_u / δ_y**	**Intital Stiffness Pu/δ_y kN/mm**	**Energy absorption (kN-mm)**
HSBC1	11	9.5	24	15.01	1.58	2.526	208.615
HSBC2	10	10.25	24	15.53	1.515	2.34	207.30
HSFBC1	10.5	9.59	21.5	13.69	1.344	2.278	149.025
HYFBC1.1	11	7.73	22	13.82	1.504	2.394	151.66
HYFBC1.2	11.5	9.69	19.5	19.45	1.628	1.632	256.66
HSFBC2	11.5	9.44	23	16.41	1.55	2.18	198.405
HYFBC2.1	15	9.19	24	16.86	1.75	2.503	257.955
HYFBC2.2	11	11.95	21	20.81	1.58	1.604	240.90

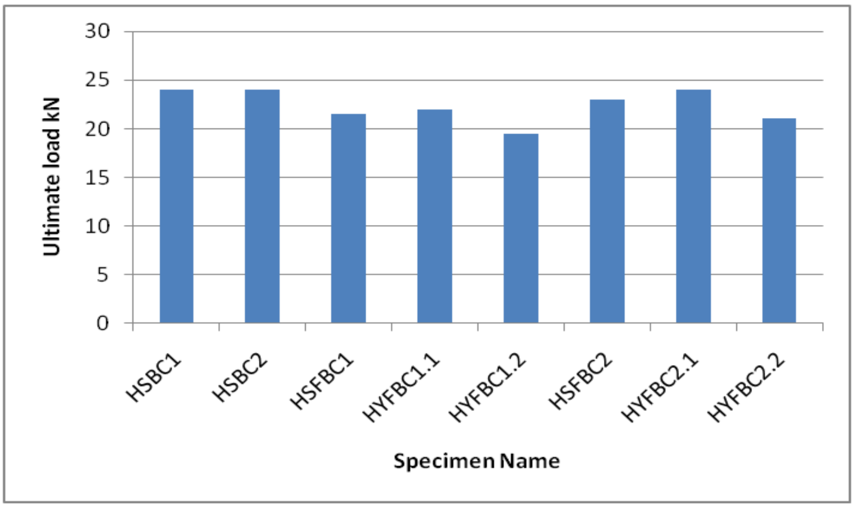
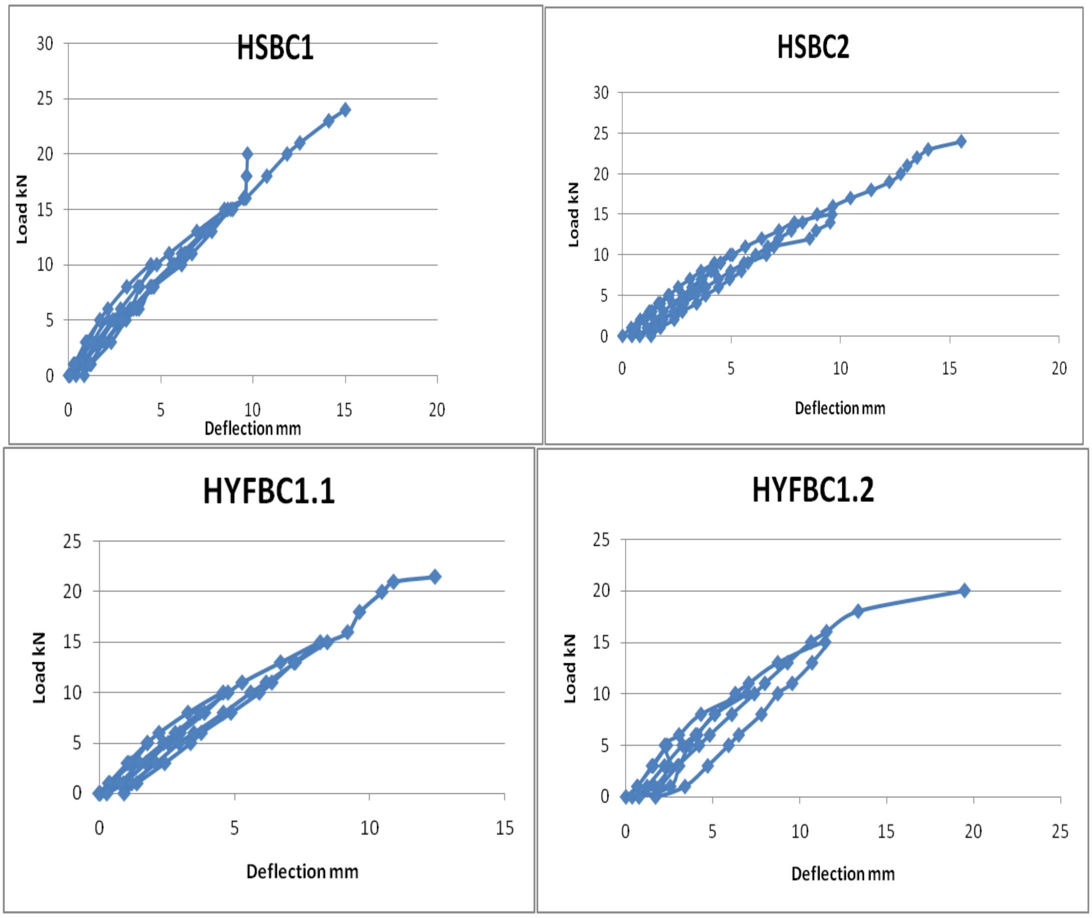


Figure 6. Ultimate load



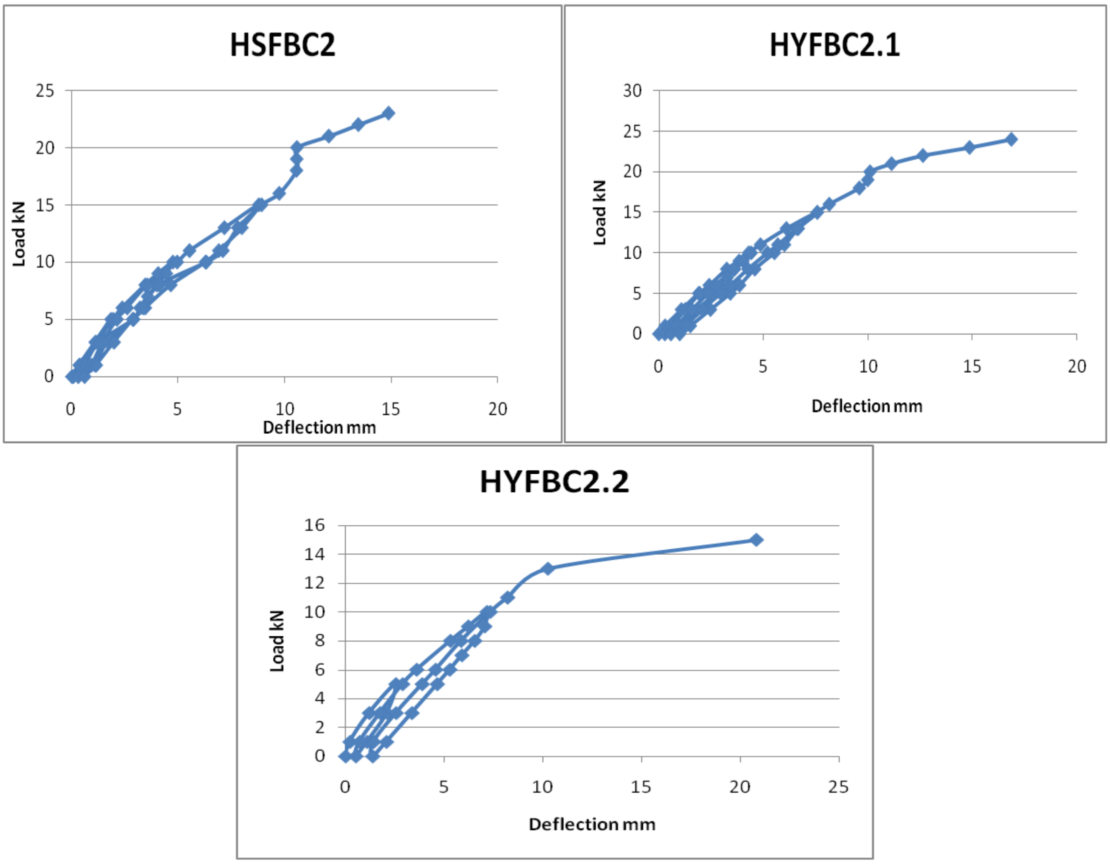


Figure 7. Cyclic behaviors of exterior beam-column joints

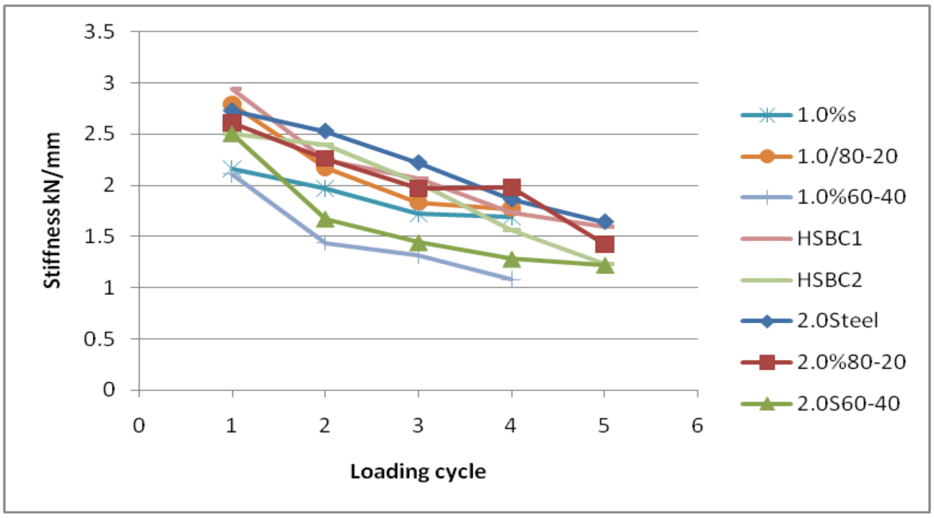


Figure 8. Stiffness degradation chart

Figure 9. Crack pattern of beam – column joints specimens after failure

4. CONCLUSION

Performance of seismic detailing high strength concrete, non-seismic detailing fiber and hybrid fiber reinforced high strength concrete exterior beam - column joint specimens were experimentally tested and compared. This research work aimed at development of a beam-column joint with high ductility and energy absorption capacity for the structures constructed in the seismic zones through the use of hybrid fibers in high strength concrete were reported. Based on the experimental results the following conclusions were arrived.

The ultimate load carrying capacity of steel fiber and hybrid fiber reinforced high strength concrete beam – column joint specimens increased with increase in fiber volume fractions. Ultimate load capacity of HYFBC2.1 specimen was same as control specimens.

Deflections were increased with increase in fiber volume fractions of non-seismic detailing specimens, compared with that of control specimen.

Deflection Ductility also increased with increase in fiber volume fractions.

Energy absorption capacity increased with increase in fiber and hybrid fiber reinforced high strength concrete specimens. The HYFBC2.1 specimen energy absorption capacity is more than the control specimens.

Acknowledgements: The authors would like to thank the Management of Sathyabama University for facilities provided in the Structural Engineering Laboratory, Department of Civil Engineering. Thank to students who were involved in the experimental works of this resaerch.

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