Experimental Investigation on Hybrid Steel Fiber Reinforced Concrete Beam – Column Joints Under Cyclic Loading

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ABSTRACT

An investigation on the performance of reinforced concrete beam column joints under cyclic loading is reported. Joints have been cast with adequate and deficient shear capacity and bond of reinforcements at the beam column joint. Steel Fiber Reinforced like crimped hook end have been applied on the joints in different volume fraction and aspect ratios. The column subjected to an axial force while the beams are subjected to cyclic load with controlled displacement. The displacement is increased monotonically using a hydraulic push and pull jack. The hysteretic curves of the specimen have been plotted. The energy dissipation capacity of retrofitted beam column joints with various hybrid steel fibres configurations has been compared. The results show that the strengthened beam column joint exhibit increased strength, stiffness, energy dissipation and composite action until failure.

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I. Introduction

Recent earthquakes in different parts of the world have revealed again the importance of design of reinforced concrete structures with high ductility. Strength and ductility of structures depend mainly on proper detailing of the reinforcement in beam-column joints. The flow of forces within a beam-column joint may be interrupted if the shear strength of the joint is not adequately provided. Under seismic excitations, the beam-column joint region is subjected to horizontal and vertical shear forces whose magnitudes are many times higher than those within the adjacent beams and columns. Conventional concrete loses its tensile resistance after the formation of multiple cracks. However, fiber concrete can sustain a portion of its resistance following cracking to resist more cycles of loading. Beam-column joints have a crucial role in the structural integrity of the buildings. For this reason they must be provided with adequate stiffness and strength to sustain the loads transmitted from beam and columns. The formation of plastic hinges in columns must be prevented since it affects the entire structure. For adequate ductility of beam-column joints, use of closely spaced hoops as transverse reinforcement was recommended in the ACI-ASCE Committee 352 report (ACI, 2002). Due to the congestion of reinforcement, casting of beam-column joint will be difficult and will lead to honeycombing in concrete (Kumar et al., 1991).

II. Significance of Study

Modeling An FRC sub-category named Engineered Cementitious Composite (ECC) claims 500 times more resistance to cracking and 40 percent lighter than traditional concrete.[citation needed] ECC claims it can sustain strain-hardening up to several percent strain, resulting in a material ductility of at least two orders of magnitude higher when compared to normal concrete or standard fiber-reinforced concrete. ECC also claims a unique cracking behavior. When loaded to beyond the elastic range, ECC maintains crack width to below 100 μm, even when deformed to several percent tensile strains. Field results with ECC and The Michigan Department of Transportation resulted in early-age cracking.

Recent studies performed on a high-performance fiber-reinforced concrete in a bridge deck found that adding fibers provided residual strength and controlled cracking. There were fewer and narrower cracks in the FRC even though the FRC had more shrinkage than the control. Residual strength is directly proportional to the fiber content.

A new kind of natural fiber-reinforced concrete (NFRC) made of cellulose fibers processed from genetically modified slash pine trees is giving good results [citation needed]. The cellulose fibers are longer and greater in diameter than other timber sources. Some studies were performed using waste carpet fibers in concrete as an environmentally friendly use of recycled carpet waste. A carpet typically consists of two layers of backing (usually fabric from polypropylene tape yarns), joined by $CaCO_3$ filled styrene-butadiene latex rubber (SBR), and face fibers (majority being nylon 6 and nylon 66 textured yarns). Such nylon and polypropylene fibers can be used for concrete reinforcement. Other ideas are emerging to use recycled materials as fibers: recycled Polyethylene terephthalate (PET) fiber, for example.

Steel fibre-reinforced shotcrete (SFRS) is a kind of spray concrete (shotcrete) with steel fibres added.

III. Objective

a) To investigate the mechanical properties like split tensile strength and compressive strength of hybrid SFRC.

b) To investigate ductility requirement, moment rotation capacity, energy absorption capacity for beam column joints under cyclic loading using hybrid steel fibers of different volume fractions.

The scope of the work is to study the behaviour of steel fibre reinforced concrete beam - column joints under cyclic loading. The parameters investigated are

a) Beam End Deflection
b) Strain measurement and
c) Location of crack occurrence

IV. Methods & Materials Cement

Ordinary Portland cement of 53 Grade confirming to IS 12269-1987 was used. The properties of the cement used were

(a) Fineness of cement by Sieve analysis
fineness Inde = 3.9 %
(b) Normal consistency = 32 %
(c) Initial setting time = 45 Min 30 Secs
(d) Specific gravity = 3.15
(e) Compressive strength at an
age of 28 days = 38 N/mm^2

A. *Aggregates*

The properties of coarse aggregates and fine aggregates are given below

B. *Coarse Aggregates*

10 mm maximum size broken granite metal of igneous origin was used. Specific gravity was found to be 2.65.

C. *Fine Aggregates*

Fine river sand was used. It was dried, sieved and stored. The sand which was used falls under zone second of IS383. The specific gravity was found to be 2.60.

D. *Water*

Clean water, which was free from all impurities, was used for the entire work of concrete preparation and curing

Mix Design for M30 Grade Concrete

Mix ratio	=	1: 1.12: 2.52
Cement	=	450
Fine Aggregate	=	502.2
Coarse Aggregate	=	1135.49
Water content	=	0 .4

V. Methods & Materials Cement

a) Procurement of material
b) Mix design
c) Testing(tensile, compression)
d) Design of beam –column joints
e) Pilot study of beam-column joints under cyclic loading
f) Casting and testing of SFRC beam column joints

VI. Experimental Investigation

A. Compressive Strength of Concrete

A total number of 6 cube specimens were casted under conventional concrete, after curing seventh day testing was carried out. The following Fig. shows the compressive strength testing while conducting test in Universal Testing Machine. Compressive strength of the specimens are calculated using the following formula:

Compressive strength = Load/Area of cube

B. Spilt Tensile Strength of Concrete

A total number of 6 cylindrical specimens were casted under conventional concrete, after curing seventh day testing was carried out. The following Fig. shows the split tensile strength testing while conducting test in Universal Testing Machine. Split tensile strength of the specimens are calculated using the following formula:

Split Tensile strength = $2P/\pi DL$

P – Applied load in Newton

D – Diameter in mm

L – Length in mm

Table 1 Compressive Strength and split Strength for 28th days

S. No	Specimen	Compressive strength (N/mm^2)	Split tensile strength (N/mm^2)
1	M1	38	3.11
2	M2	42	5.18
3	M3	39	3.63
4	M4	41	4.57
5	M5	43	5.22
6	M6	52	8.37
7	M7	50	7.14
8	M8	47	6.29

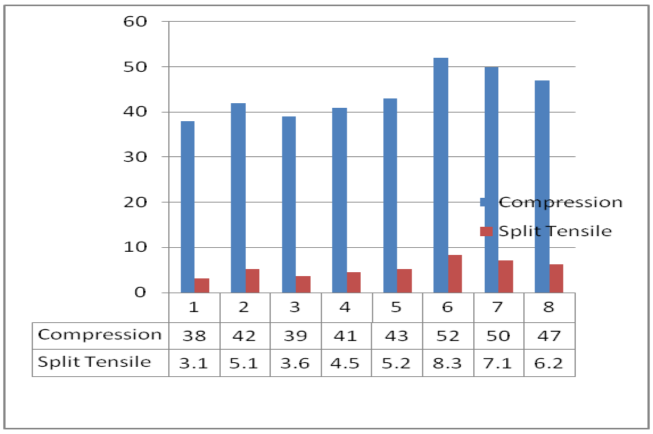

Fig 1 Compressive Strength and split Strength for 28th days

C. Cyclic Loading

Cyclic Load analysis is the application of incremental Push and Pull Load. The analysis is also known as Push-Pull loading . The loads are applied incrementally as positive and negative loads.

D. Test Programme

The project deals with the behaviour of hybrid steel fibre reinforced concrete beam-column joints subjected to cyclic loading. Cyclic Load analysis is the application of incremental Push and Pull Load. The analysis is also known as Push-Pull analysis. The loads are applied incrementally as positive and negative loads.To find out Beam End Deflection, Strain measurement and Location of crack occurrence is the prime concern of this study

The beam-column joints were tested under cyclic loading. These beam-column joints were divided M1, M6, M7, and M8. Set M1 contains two beam-column joint with strength of concrete

Set M6 contains two beams-column joint with Crimped + H1 (Aspect ratio 50+80 & volume fraction 0.5%+0.5%) and grade of concrete fixed as M30.

Set M7 contains two beams-column joint with Crimped + H2 (Aspect ratio 50+65& volume fraction 0.5%+0.5%) and grade of concrete fixed as M30.

Set M8 contains two beams-column joint with Crimped + H3 (Aspect ratio 50+45& volume fraction 0.5%+0.5%) and grade of concrete fixed as M30.The investigated parameters under this study To Investigate ductility requirement, moment rotation capacity, energy absorption capacity for beam column joints under cyclic loading using hybrid steel fibers of different volume fractions . Further details of beam-column joint specimens are as follows.

E. Details of Specimens

The details of specimen of different volume fraction and aspect ratio are given in table 2

Table 2 Details of Specimens

S.No	Specifi cations	Number of Specimens			Volume Fraction (%)	Aspect Ratio (L/D)
		Beams -colum n joint	Cylinders	Cubes		
1	M1	2	6	6	----	----
2	M2	-	6	6	1%	50
3	M3	-	6	6	1%	80
4	M4	-	6	6	1%	65
5	M5	-	6	6	1%	45
6	M6	2	6	6	(0.5+0.5) %	50+80

7	M7	2	6	6	(0.5+0.5) %	50+65
8	M8	2	6	6	(0.5+0.5) %	50+45
TOTAL		8	48	48		

M1-Control beam
M2-Crimped fiber alone (Aspect ratio 50 & volume fraction 1%)
M3-H1 alone (Aspect ratio 80 & volume fraction 1%)
M4-H2 alone (Aspect ratio 65 & volume fraction 1%)
M5-H3 alone (Aspect ratio 45 & volume fraction 1%)
M6-Crimped + H1 (Aspect ratio 50+80 & volume fraction 0.5%+0.5%)
M7-Crimped + H2 (Aspect ratio 50+65 & volume fraction 0.5%+0.5%)
M8-Crimped + H3 (Aspect ratio 50+45 & volume fraction 0.5%+0.5%)
H - HOOKED END STEEL FIBRE.

Description of beam-column joint

1. No. of Beams = 8
2. Cross section = 100 mm x 100 mm
3. Concrete strength = M30
4. Reinforcement details are shown

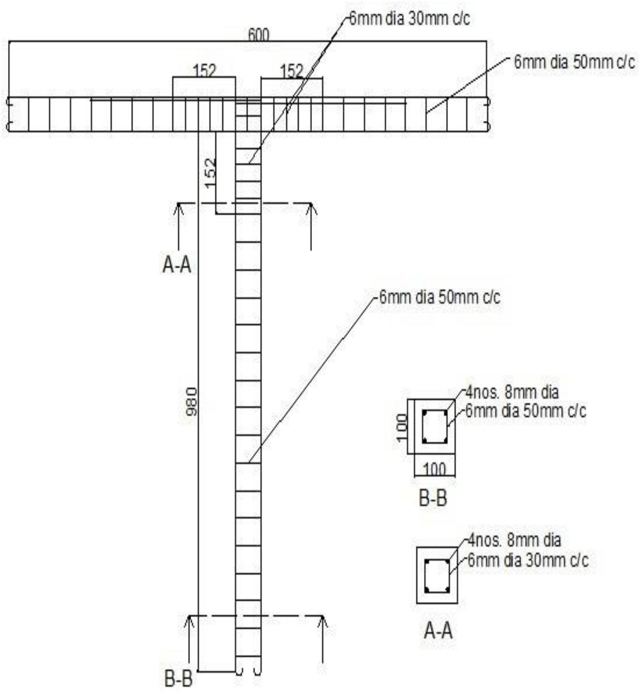

Fig 2 Reinforcement Details of Beam-column joint

Conduct of Experiment

The experiment was conducted in the following manner.

a) The beam-column joint to be tested was lifted and kept in the loading platform. Example (Fig. 3 & 4)

Fig 3 Experimental setup for Beam Column joint

Fig 4 Testing of Beam column joint

Fig 5 Side view of loading frame with testing specimen

a) The beam column was so adjusted that the centers to the load cell
b) The testing was done in a loading frame. Load was applied by means of a hydraulic jack of capacity 25

tones. The load was measured using a load cell of 5 tones capacity.

c) Deflection of the joints were measured for every o.2 Ton by using dial gauges which are fixed at both the sides , with a least count of 0.01mm.

d) the arrangement has been made ready for performing the experiment and the dial gauges were also set for zero reading.

e) 5T capacity load cell was placed above the hydraulic jack in the center.

VII. Results & Discussion

A. Results of Testing of Beam-Column Joints

The observations from the testing of Beam column joint are given in Appendix B of this report. The observations were processed and graph plotted between the load and deflections.The hysteretic Curves of the specimen have been plotted.The Energy dissipation capacity of Beam Column joints with various hybrid steel fibres.

B. Test Results of Beam-Column Joint (M1)

From the experiment it has been found that the first crack was formed at a load of 0.6 tonne. The ultimate load that for normal concrete can carry was 1.6 tonne. The hysteretic Curves of the specimen have been plotted in Fig.6 respectively.

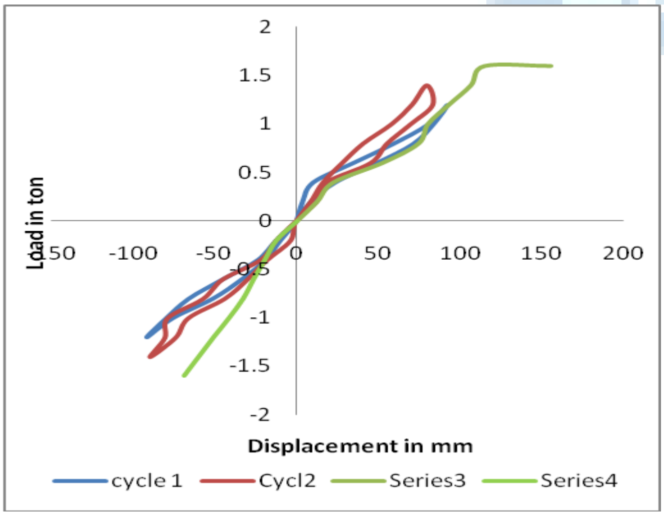

Fig 6 Cyclic Load - Deflection Curve for beam-column joint (M1)

The energy dissipation are calculated from the load - deflection curve is found to be 41.837kN/m.

C. Test Results of Beam-Column Joint (M2)

From the experiment it has been found that the first crack was formed at a load of 0.8 tonne. The ultimate load for ductile detailing can carry was 1.9 tonne. The hysteretic Curves of the specimen have been plotted in Fig.s 7 respectively.

D. Test Results of Beam-Column Joint (M5)

From the experiment it has been found that the first crack was formed at a load of 1.4 tonne. The ultimate load for hybrid (CR+HE) can carry was 2.4 tonne. The hysteretic Curves of the specimen have been plotted in Fig. 8 respectively

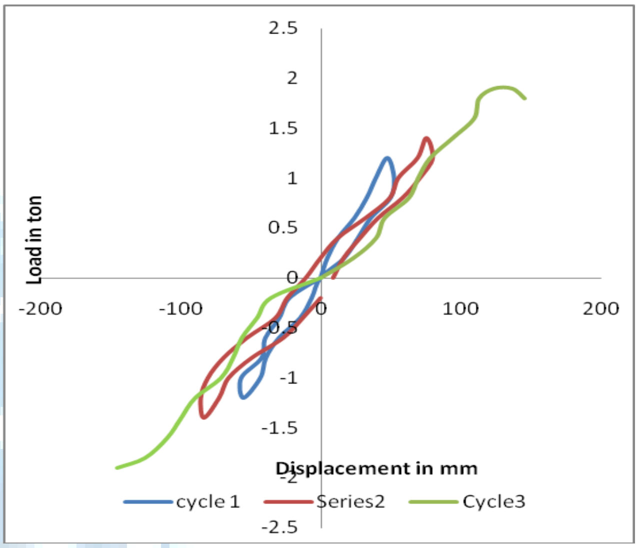

Fig 7 Cyclic Load - Deflection Curve for beam-column joint (M2)

The energy dissipation are calculated from the load - deflection curve is found to be 73.97kN/m.

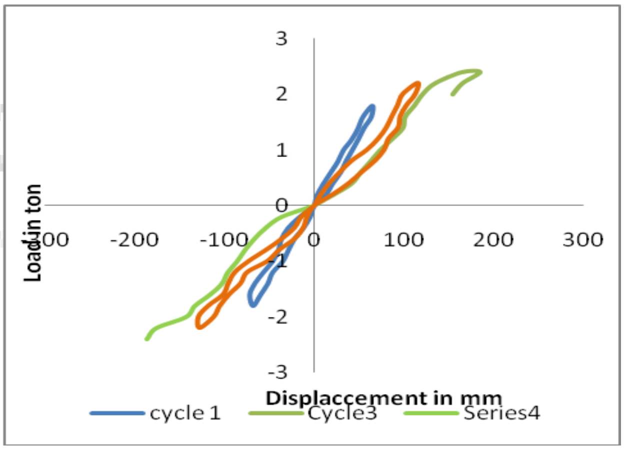

Fig 8 Cyclic Load - Deflection Curve for beam-column joint (M5)

The energy dissipation are calculated from the load - deflection curve is found to be 116.97 kN/m.

E. Test Results of Beam-Column Joint (M8)

From the experiment it has been found that the first crack was formed at a load of 0.9 tonne. The ultimate load for hybrid (HE+HE) can carry was 2 tonne. The hysteretic

Curves of the specimen have been plotted in Fig.s 5.4 respectively.

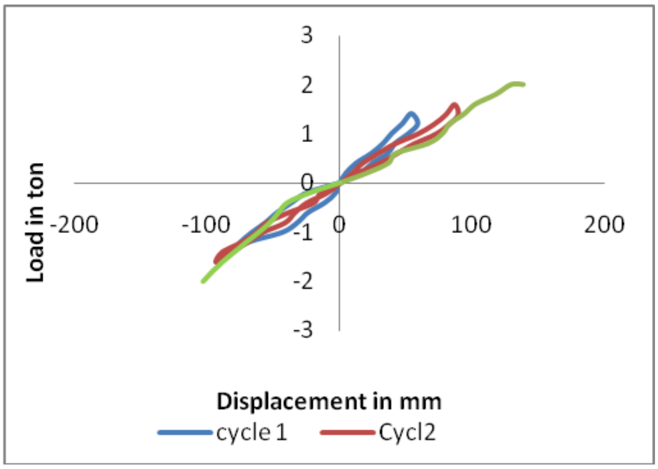

Fig 9 Cyclic Load - Deflection Curve for beam-column joint (M8)

The energy dissipation are calculated from the load - deflection curve is found to be 92.711kN/m.

DISCUSSIONS

From the experiments carried out, it is observed that the use of Hybrid Steel Fibers increases the Strength energy dissipation, The increases cumulative energy dissipation is 28.3 % for non-ductile and 31.6 % for ductile reinforced concrete beam column joint strengthen by Hybrid Steel Fibers Fig. 5.5 shows the Comparison of Cyclic Load - Deflection Curve for beam-column joint

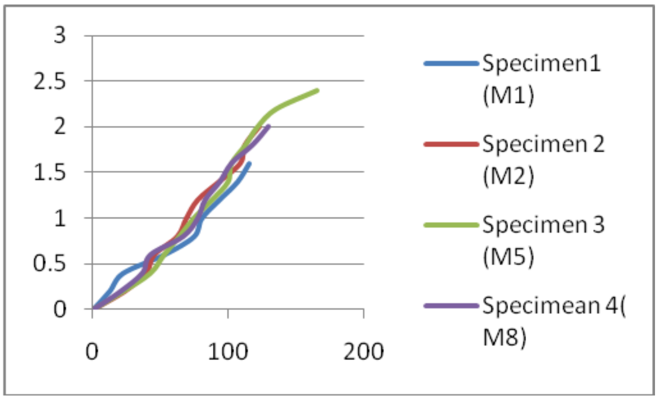

Fig 10 Comparison of Cyclic Load - Deflection Curve for beam-column joint

I. Conclusion

The behavior of beam column joints were studied in the present work and it has been concluded that

a) Based on the behavior of joints under the loads, it is concluded that the use of hybrid steel fibers gives us optimum value for exterior joints
b) The interaction between ultimate loads and degree of confinement are not linear. This has to be further investigated.
c) The Hybrid Steel fibers can be efficiently used for seismic reinforced beam column joint.
d) The deficiency in cumulative energy dissipation in the case of non ductile reinforced beam column joint can be made good by Hybrid Steel fibers strengthening.
e) The increase in cumulative energy dissipation is 28.3 percent for non ductile and 31.6 percent for ductile reinforced concrete beam column joint strengthened by Hybrid Steel fibers.
f) Much of experimental investigation is needed in the direction of establishing a relationship between confinement reinforcement's volume and the region of extent to which this provided on the stiffness and ultimate load characteristics of joints.
g) Joints with high strength may be investigated

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