Effect of Steel Fibre Reinforced High Performance Concrete Exterior Beam Column Joint Subjected To Cyclic Loading

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Abstract— **Beam-column joint is a typical lateral and vertical load resisting member in reinforced concrete structures which are mainly prone to failures during earthquake. Their constituent materials have limited strength and the joints have limited force carrying capacity. When forces larger than these are applied during earthquake, joints are severely damaged. In this study M50 grade high performance concrete for 5%, 7.5%, 10% and 12.5% replacement of cement with silica fumes were prepared and comprehensive tests have been conducted to find its strength and resistance to chloride ion penetration. The optimum replacement percentage of silica fume was found out and is then used to cast high performance concrete (HPC) exterior beam column joints. The optimum volume fraction of steel fibre in HPC was found out to be 1%. A comparative study between behaviour of steel fibre reinforced high performance concrete (SFRHPC) and High performance concrete exterior beam column joints subjected to cyclic loading were carried out. It was found that the ultimate load of SFRHPC exterior beam column joints were 15.3% higher than HPC beam column joints. The total energy absorption capacity of SFRHPC specimens were 37% more than HPC specimens. The displacement ductility factor of SFRHPC specimen was 9.83% higher than HPC specimens and the curvature ductility factor of SFRHPC specimen was 9.61% higher than HPC specimens. Results showed a better performance for SFRHPC exterior beam column joint compared to HPC exterior beam column joint subjected to cyclic loading.**

Keywords—High performance concrete, Steel fibre reinforced high performance concrete, Silica fume, Chloride ion, Energy absorption capacity, Ductility factor

I. INTRODUCTION

Recently, a large number of concrete highway bridges, concrete dams and nuclear power plants and other offshore structures have been vastly constructed in many countries. These structures constructed during the past have suffered from safety and serviceability problems due to deterioration of concrete, and thus the durability of concrete has received great importance. Although concrete is a very durable material, the environmental factors such as weathering action, chemical attack, abrasion and other deterioration processes may change the properties of concrete with time, and the structures finally reach the end of service life due to lack of safety and serviceability. Any concrete which satisfies certain criteria proposed to overcome limitations of conventional concretes may be called high performance concrete [1]. Since high resistance to chloride penetration can be directly related to low permeability that dominates the deterioration process in concrete structures, the resistance to chloride penetration is one of the simplest measures to determine the durability of concrete. Thus, high-performance concrete is a concrete having high resistance to chloride penetration as well as high strength. The presence of micro cracks in the mortar -aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mixture [2]. The addition of fibres to concrete has been shown to increase strength, ductility and fatigue strength of concrete. When fibres are added to concrete, tensile strain in the neighbourhood of fibres improves significantly [3]. Fibre reinforced high performance concrete can be effectively used in RCC members subjected to extreme loading conditions such as seismic loading, blast loading and impact loading. In Reinforced Concrete buildings, portion of columns that are common to beams at their intersections are called Beam-Column joint. Beam-column joint is a typical lateral and vertical load resisting member in reinforced concrete structures which are mainly prone to failures during earthquake [4]. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged. Repairing damaged joints is difficult, and so damage must be avoided. Thus, beam-column joints must be able to resist earthquake effects.

II. SCOPE OF THE STUDY

In this study high performance concrete (HPC) of design strength 50MPa for 0%, 2.5%, 5%, 7.5%, 10% and 12.5% replacement of cement with silica fumes are to be prepared and comprehensive tests are to be conducted to find the hardened mechanical properties and resistance to chloride ion penetration. The optimum replacement percentage of silica fume is to be found out and is then used to cast high performance concrete exterior beam column joints. Three volume fractions 0.5%, 1%, 1.5% of steel fibre were studied and the optimum volume fraction of steel fibre was found out and it is then used to prepare SFRHPC exterior beam column joint. This study aims at finding the behaviour of SFRHPC exterior beam column joint subjected to cyclic loading.

III. EXPERIMENTAL INVESTIGATION

A. *Determination of properties of materials*

Define The constituent materials consist of Portland Pozzolana Cement (PPC) of standard consistency 34percent, specific gravity 2.9 with 28 day compressive strength 33MPa, Quarry sand confirming to Zone II of IS:383 (1970) as fine aggregate, and coarse aggregate of 20mm nominal size [5]. The water absorption of natural coarse aggregate was found to be 1 percent. Tests were conducted as per IS 2386 -part III (1963) for fine aggregate and as per IS:383(1970) for coarse aggregate to determine the different physical properties and are tabulated in Table 1 [6]. The superplasticizer used was CONPLAST SP-430 superplasticizer of specific gravity 1.18 and the specific gravity of silica fume used was 2.2. The chloride and sulphide content in water were found to be 17.5mg/l and 8mg/l respectively. The steel fibre used was crimped steel fibre with an aspect ratio of 50. Mechanical properties, namely, compressive strength, tensile strength, modulus of elasticity and modulus of rupture were determined.

TABLE 1. PROPERTIES OF AGGREGATES

Properties	**Fine aggregate**	**Coarse Aggregate**
Specific gravity	2.47	2.76
Sieve analysis	Conforming to zone II of IS:383(1970)	Conforming to 20 mm graded aggregate IS:383(1970)
Water absorption	1.75 percent	0.75 percent
Bulk density	1710 kg/m^3	1540 kg/m^3
Fineness Modulus	2.75	5.99

B. *Mix Proportioning*

Proportioning of constituents was carried out by the method proposed by Aïtcin [7]. The method itself is very simple and it follows the same approach as ACI 211–1(1991) Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete [8]. It is a combination of empirical results and mathematical calculations based on the absolute volume method. The water contributed by the superplasticizer is considered as part of the mixing water. The mix proportions for various mixes for 1m3 concrete is given in Table.2.

Workability tests were conducted using slump test, for fresh concrete as per IS specifications, keeping the dosage of superplasticizer as constant at 2 percent by weight of binder. For the compressive strength determination, 150mm x150mm x150mm specimens were used. 150mm diameter and 300 mm height cylinders were used for determining the split tensile strength and modulus of elasticity. The flexural tensile strength test prisms of size 100mmx100mm x500mm were used. All the specimens were moist cured underwater at room temperature until testing. Each strength value was the average of the strength of three specimens. The optimum volume fraction addition of steel fibre on high performance concrete was found out using workability test by maintaining a contant slump of 120mm by varying the super plasticizer dosage for varying volume fraction addition of steel fibers used for the study.

TABLE 2. MIX PROPORTION FOR VARIOUS MIXES

Volume replacement ratio of Silica Fume (%)	Water (kg)	Cement (kg)	Silica Fume (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	Super plasticizer (liters)
0	163	455	0	1070	680	9.5
2.5	163	443	11	1070	680	9.5
5.0	163	432	23	1070	680	9.5
7.5	163	420	35	1070	680	9.5
10.0	163	410	45	1070	680	9.5
12.5	163	400	32	1070	680	9.5

C. *RCPT test for finding the chloride ion penetration*

In order to find the chloride ion penetration of HPC, Rapid Chloride ion Penetration Test (RCPT) was conducted as per ASTM C 1202 as shown in Table 3 [9]. For this, specimens of size 100mm diameter and 50mm thick were prepared. After 28 days of curing, the specimens were coated with epoxy and were vacuum saturated for 3 hours and then soaked for 18 hours. The specimens were then placed in the testing apparatus, where one end of the specimen is exposed to a solution containing sodium chloride (NaCl) and the other end is exposed to a solution containing sodium hydroxide (NaOH). To increase the rate of chloride penetration into the specimen, thus speeding up the test, a constant 60 V potential is applied across the specimen. . The current across the specimen is measured at an interval of 30 minutes during the 6-hour test and the results obtained were then compared with standard values. Berke's equation was used to calculate the Chloride Migration Diffusion Coefficient.

TABLE 3. CHLORIDE ION PERMEABILITY BASED ON CHARGE PASSED

Charge passed(coulombs)	**Chloride ion penetrability**
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

D. *Test on Exterior Beam Column Joint*

In the beam column joint, column dimension is 200mmx200mm cross -section and 1m length, beam dimension is 150mmx 200mm cross-section and 80 cm length. The reinforcement detailing as shown in Fig. 1 includes 4 numbers of 10mm dia. bars for column and 2 numbers of 8mm dia. bars at top and 2 numbers of 10mm dia. bars at the bottom for beam and 6mm stirrups are provided at a spacing of 120 mm c/c. The number of exterior beam column joints used for the study includes 3 numbers of HPC specimens and 3 numbers of SFRHPC specimens.

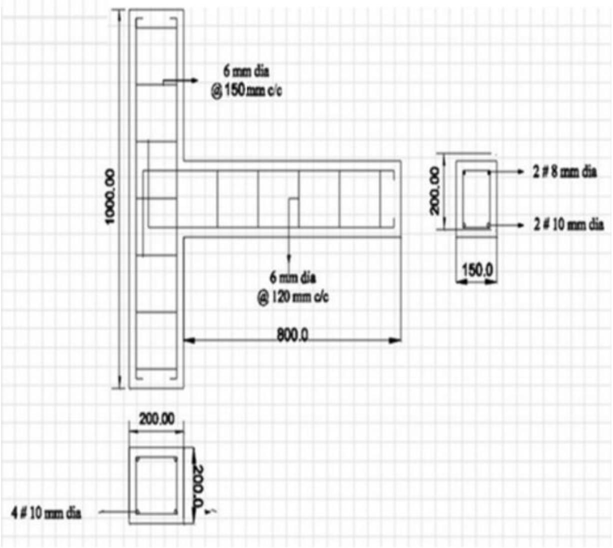

Figure 1. Detailing of reinforcement

The exterior beam column joint test setup is as shown in Fig. 2. From the observed results, Load deflection graph was plotted from which envelope curve, energy absorption, stiffness degradation and displacement ductility factor was found out for HPC and SFRHPC specimens. The strain measurements were used to obtain the moment curvature plot and curvature ductility factor.

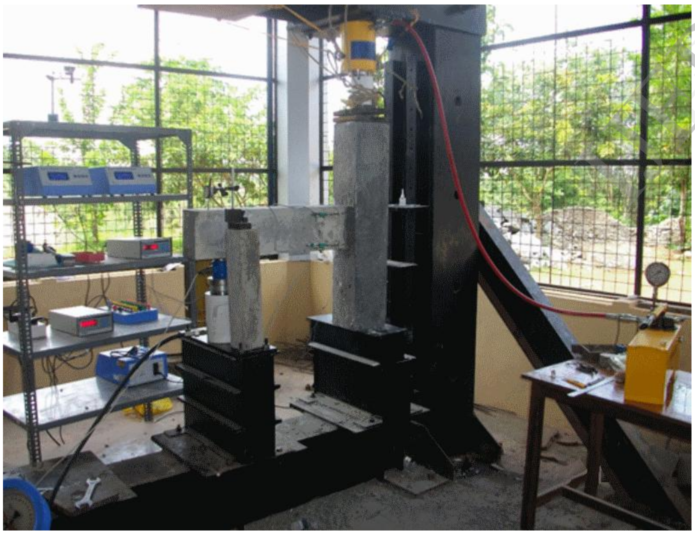

Figure 2. Exterior Beam Column Joint subjected to cyclic loading Test Setup

IV. RESULTS ND DISCUSSIONS

A. *Hardened Properties of HPC*

The results of different tests such as cube compressive strength, cylinder compressive strength, flexural strength, and modulus of elasticity for different percentage replacement of silica fume is given in Table 4. All the test results show an increasing trend up to a percentage volume replacement of 7.5%. This is due to increase in strength characteristics due to the pozzolanic reaction of amorphous silica present in the silica fume. The strength of concrete is found to be decreasing when the replacement ratio is greater than 7.5 percent. The CaO content in the silica fume is relatively lower compared to cement .Even though the strength decreases after silica fume replacement of 7.5 %, the grade of concrete required of M50 was obtained for silica fume replacement of 10 % .Since silica fume is cheaper than cement ,10% re placement of cement with silica fume is considered as optimum replacement percentage.

TABLE 4. HARDENED PROPERTIES OF HPC FOR VARYING PERCENTAGE OF SILICA FUME

Volume replacement ratio of Silica Fume (%)	**Cube Compressive Strength (N/mm^2)**	**Cylinder Compressive Strength (N/mm^2)**	**Split Tensile Strength (N/mm^2)**	**Flexural Strength (N/mm^2)**	**Modulus of Elasticity (x10^3 N/mm^2)**
0	54.0	42.0	3.1	6.4	32
2.5	57.5	44.5	3.2	6.4	32.5
5.0	61.0	46.0	3.2	6.9	33
7.5	62.5	49.5	3.6	7.4	35.5
10.0	60.0	48.5	2.9	6.2	34
12.5	54.0	41.5	2.8	5.4	30

B. *Result of RCPT Test on Hpc*

The total charge passed through the concrete specimen was found to be decreasing with increase in percentage replacement of cement with silica. The chloride diffusion coefficients shows that the specimen with highest replacement had the lowest diffusion coefficient and specimen with minimum replacement had the highest diffusion coefficient. From this, it can be inferred that the chloride ion penetration and the diffusion coefficient decreases as the replacement percentage increases. The better chloride resistance of silica fume blended concretes is due to high refinement of the pore structure. The charge passed through each specimen and diffusion coefficient for varying replacement percentage of silica fume is given in Table 5.

TABLE 5. CURRENT PASSED THROUGH EACH SPECIMEN AND DIFFUSION COEFFICIENT

Percentage Replacement	**Calculated Charge (Coulombs)**	**Corrected Charge (Coulombs)**	**Chloride Ion Penetrability**	**Chloride Diffusion Coefficient**
0	1082.7	974.43	Very Low	3.34×10^{-12}
2.5	945.7	851.2	Very Low	3.34×10^{-12}
5.0	917.1	825.4	Very Low	2.90×10^{-12}
7.5	823.5	741.1	Very Low	2.65×10^{-12}
10.0	774.3	686.8	Very Low	2.48×10^{-12}
12.5	661.5	595.4	Very Low	2.20×10^{-12}

C. Exterior Beam Column Joint Subjected to Cyclic Loading Test Results

1) Behaviour of Specimens

In all specimens cracks appeared at the beam column interface after the first crack load. With further increase in loading, the crack propagated and the initial crack started widening. The ultimate load and corresponding deflection of specimens were found to increase as the fibre content increased. The typical failure pattern of HPC and SFRHPC beam column joints are shown in Figure 3 and Figure 4 respectively

Figure 3. Failure pattern of HPC beam column joint subjected to cyclic loading

Figure 4. Failure pattern of SFRHPC beam column joint subjected to cyclic loading

2) Ultimate Load

The first crack load and ultimate load of HPC and SFRHPC have been found out and are given in Table 6. The results shows an increase of about 12.5% in the first crack load and 15.3% in the ultimate load for the SFRHPC specimens compared to HPC specimens. When the micro cracks develop in the matrix, fibres intercept the cracks and prevent them from propagating in the same direction. Hence the cracks need to take a deviated path which requires more energy for further propagation, thus resulting in higher load carrying capacity.

TABLE 6. FIRST CRACK LOAD AND ULTIMATE LOAD OF HPC AND SFRHPC BEAM COLUMN JOINT

Specimen	First Crack Load (kN)	Ultimate Load (kN)
HPC	8	21.5
SFRHPC	9	24.8

3) Load Deflection Behaviour

The load deflection plot of HPC and SFRHPC exterior beam column joints subjected to cyclic loading are shown in Fig. 5 and Fig. 6 respectively. It can be seen that the stiffness decreases with increase in load value for both HPC and SFRHPC exterior beam column joint. The envelope curve is obtained by joining the peak points of each cycle. Important parameters like energy absorption capacity, stiffness, displacement ductility factor were evaluated from this load deflection plot.

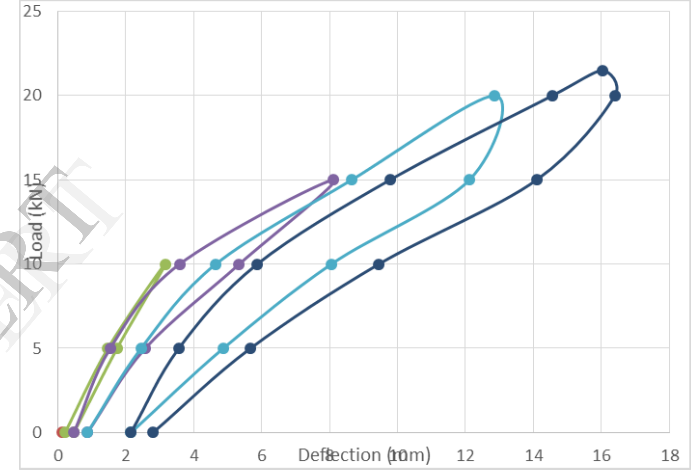

Figure 5. Load Defection Plot of HPC specimen

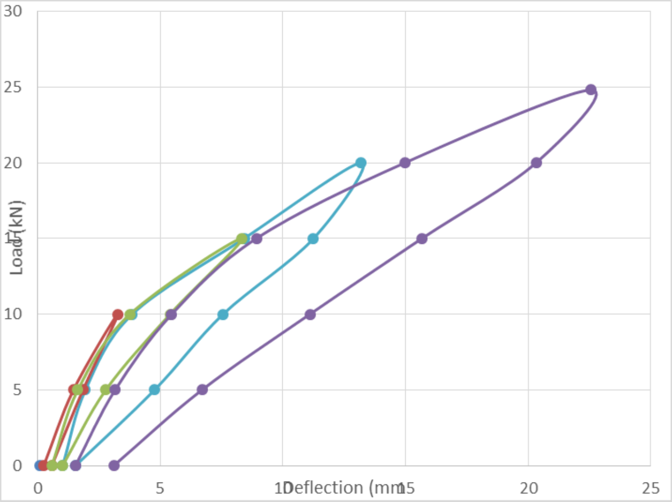

Figure 5. Load Defection Plot of SFRHPC specimen

4) Energy Absorption Capacity

The area under the load deflection curve represents the energy absorption capacity of the specimen. The energy absorption during each cycle of HPC and SFRHPC load deflection curve is given in Table 7. The total energy absorption capacity of HPC and SFRHPC specimens were 737.74kNmm and 1011.34kNmm respectively.

TABLE 7. ENERGY ABSORPTION CAPACITY OF HPC AND SFRHPC IN EACH CYCLE

Cycle No.	Energy absorbed in each cycle (kNmm)	
	HPC	**SFRHPC**
1	6.85	7.55
2	29.3	30.43
3	134.5	135.85
4	238.25	268.05
5	328.5	570.97

5) Stiffness

Stiffness is defined as the load required to cause unit deflection of the beam-column joint. The stiffness in each cycle was calculated using a line drawn between the maximum positive displacement point in one half of the cycle and the maximum negative displacement point in the other half of the cycle. Comparing all the specimens , similar degradation trends were observed in HPC and SFRHPC specimens.

6) Displacement Ductitlity Factor

Ductility of a structure is its ability to undergo deformation beyond the initial yield deformation while still sustaining load.

$$\text{Ductility factor} = \frac{\text{Ultimate displacement}}{\text{Yield displacement}} \qquad [10]$$

The yield displacement is equal to the displacement corresponding to yield load which is 75% of ultimate load [26]. The displacement ductility factor of HPC and SFRHPC specimens are shown in Table 8. It was found that the displacement ductility factor of SFRHPC specimen was 9.83% greater than HPC specimen

7) Moment Curvature Behaviour

The values of moment M were calculated using the experimental values of load and lever arm. The moment M, curvature ductility Φ at peak load and yield load are shown in Table 8. The values of M and Φ were used to plot the moment curvature were used to obtain moment curvature plot for the joint. Fig. 6 and Fig. 7 shows the moment curvature plot for the HPC and SFRHPC exterior beam column joint respectively.

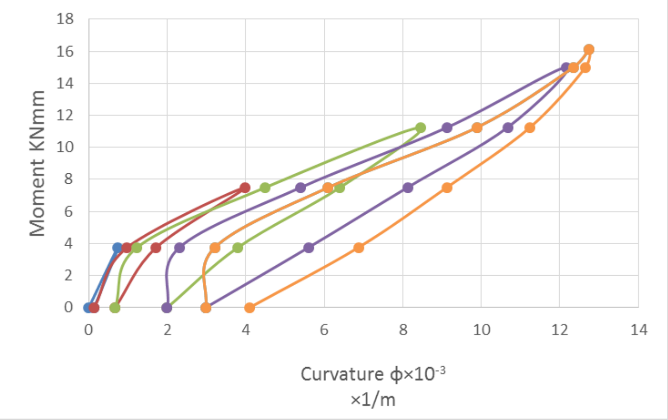

Figure 6. Moment Curvature Plot for HPC Exterior Beam Column Joint

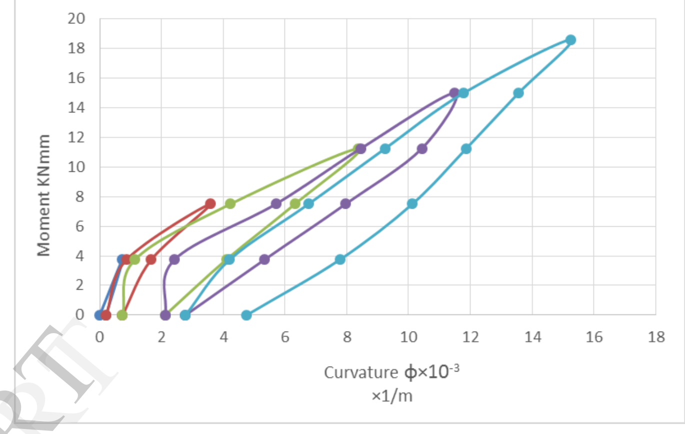

Figure 7. Moment Curvature Plot for SFRHPC Exterior Beam Column Joint

8) Curvature Ductility Factor

The capacity of the member to deform beyond its initial yield deformations with minimum loss of strength and stiffness depends upon the ductility factor which is defined as the ratio of the ultimate deformation to its yield deformation at first yield. The curvature ductility factor for HPC and SFRHPC exterior beam column joint were found out as shown in Table 8.

TABLE 8. MOMENT AND DUCTILITY FACTORS OF HPC AND SFRHPC SPECIMEN

Specimen	**Displacement Ductility Factor**	**Curvature at Ultimate Load × 10^{-3} rad/m**	**Moment at Ultimate Load (kNm)**	**Curvature Ductility Factor**
HPC	1.73	12.75	16.125	1.31
SFRHPC	1.9	15.24	18.6	1.436

V. CONCLUSION

- In HPC, 10% replacement of cement with silica fume was found out as the optimum replacement percentage.
- The chloride ion penetration decreases with increase in replacement percentage of silica fume.
- The optimum volume fraction of steel fibre was found out as 1%.
- The chloride ion penetration for SFRHPC specimens was higher than HPC specimens.
- There was an increase of about 12.5% in the first crack load and 15.3% in the ultimate load for the SFRHPC compared to HPC exterior beam column joint specimens when subjected to cyclic loading.
- The total energy absorption capacity of SFRHPC specimens were 37 % more than HPC specimens.
- The stiffness degradation of SFRHPC specimen was less than HPC specimens for the first 4 cycles and was more for the last cycle.
- Displacement ductility factor of SFRHPC specimen was 9.83% higher than HPC specimens.
- Curvature ductility factor of SFRHPC specimen was 9.61% higher than HPC specimens.

Thus it was found that SFRHPC exterior beam column joint had better performance when compared to HPC exterior beam column joint.

VI. ACKNOWLEDGMENT

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