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# Seismic and Structural Behavior of RCC Beams Made With Hybrid Fiber Reinforced Self Consolidating Concrete

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***Abstract - Concrete is one of the significant building materials in the field of construction which plays an important role that it provides strength and durability properties to the structure. In recent days, modern construction is to improve the above mentioned properties of concrete with the available sustainable building materials. Self consolidating concrete (SCC) has the ability to make a viscous concrete which can be considered as the pump able concrete with no segregation and compacted itself by its own weight. In this study, fly ash based SCC of grade M40 (1:1.85:1.14) was considered to produce RCC beams of cross section 150 x 200mm of length 1800mm. In order to increase the strength of SCC and to minimize the effect of micro cracks in the RCC beams, hybrid fibers which compose of steel and polypropylene fibers were added into the concrete mixes. Totally 12 beam specimens were prepared with fiber reinforced SCC to check the structural behavior of RCC beams. Finite element modeling software package of ANSYS was used to analyze the structural behavior of RCC beams numerically and the results were compared with the experimental results. From the experimental investigation, the seismic behavior of RCC beams under varying loading condition was examined such as ductility factor, energy absorption capacity and stiffness degradation of the beams.***

***Keywords: SCC, Hybrid Fibers, Structural Behavior, Seismic Behavior.***

## I. INTRODUCTION

SCC is a concrete which possess fluidity in nature that does not require vibration and, in fact, must not vibrate. Viscous nature of the SCC was influenced by Fly ash from nearby power plant that acts as viscosity modifying agent (VMA) [1] [2]. As the fines increase, the volume of the paste in the SCC increases, causing significant shrinkage and creep. It uses super plasticizers and VMA to significantly increase the strength properties and rate of flow. It compresses each part of the mould simply by its self weight without causing segregation and bleeding [1] [4].

Fiber reinforced SCC (FRSCC) is a new construction material which combines the benefits of SCC with fiber in concrete. It is a ductile material that enters the formwork freshly, fills it naturally, crosses obstacles and solidifies under the effect of its own weight [3]. Based on the recent investigations, most of the researchers studied in detail the behavior of SCC with different compositions of materials and different volume fractions of the fiber content. Quite studies have been conducted on FRSCC to evaluate the optimum fiber content in the conventional SCC to improve the strength performance. Only sustainability studies have been conducted with FRSCC, and most studies have been done with natural or synthetic fibers used separately in concrete mixes. In this study, hybrid fibers were added to SCC, seismic and structural properties were performed on SCC under static and cyclic loading.

## II. MATERIALS USED

The lists of materials used in this study are as follows [3] [4] [5]:

***a. Cement (C)***

Ordinary Portland Cement of 53 grade was used throughout the investigation.

Table -1: Properties of Cement

| Property | Consistency | G* | Setting Time |
|---|---|---|---|
| Result | 32.5% | 3.14 | 34 min (Initial);<br>554 min (Final) |

[G* - Specific Gravity]

***b. Fine aggregate (FA)***

Naturally available clean dry river sand of Zone II was used.

Table – 2: Properties of Fine Aggregate

| Property | G* | Bulk Density | Fineness Modulus |
|---|---|---|---|
| Result | 2.47 | 1880kg/m$^3$ | 3.35 |

***c. Coarse Aggregate (CA)***

A locally available crushed stone of 20mm angular aggregate of specific gravity 2.70 was used.

***d. Fly Ash***

Fly ash from Mettur Thermal Power Plant was utilized as VMA [1].

Table 3: Properties of Fly Ash

| Property | Color | Specific Surface | Moisture content |
|---|---|---|---|
| Result | Dark Grey | 320 m$^2$/kg | 3% |

***e. Fibers (F)***

Discrete steel fiber (SF) and polypropylene fiber (PPF) of aspect ratio 40 were incorporated to produce the hybrid fibers in FRSCC [5].

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**Table – 4: Properties of Fibers**

| Property | SF | PPF |
|---|---|---|
| **Length (mm)** | 35 | 6 |
| **E* (GPa)** | 200 | - |
| **Fiber Type** | Straight & Corrugated | Monofilament |
| **Melting point** | - | 165°C |

### *f. Super Plasticizer(SP)*

Master Gelenium SKY 8233 was used to improve the workability of FRSCC.

**Table-5: Properties of Super Plasticizers**

| Property | pH | Chloride ion content | Relative density |
|---|---|---|---|
| **Result** | > 6 | < 0.2 | 1.09 |

### *g. Water(W)*

Potable drinking water was used for the entire experimentation.

## II. MIX PROPORTIONS

Mix design for M40 grade FRSCC was prepared as per the guidelines mentioned in IS 10262:2009 and it should satisfy the EFNARC specifications for SCC [7]. Steel and polypropylene fibers were added to the SCC mixes individually at the range of 0.5% to 2% at an interval of 0.5%. Table 6 illustrates the detailed mix proportions for the SCC mixes.

Addition of fibers at 2% by volume of cement, does not satisfies the workability test on SCC and concluded that based on the workability test, it was concluded that the optimum dosage of SF and PPF was found that 1.0% and 1.0% respectively.

**Table - 6: Mix Proportions (kg/m$^3$)**

| Mix ID | C | FA | CA | W | VMA | SP | W/C |
|---|---|---|---|---|---|---|---|
| **CC** | 475 | 877 | 541 | 252 | 130 | 4.75 | 0.53 |
| **SFSCC1.0** | 496 | 723 | 759 | 260 | 145 | 5.46 | 0.52 |
| **PFSCC1.0** | 484 | 869 | 631 | 259 | 144 | 5.57 | 0.54 |
| **HFSCC1.0** | 518 | 755 | 644 | 273 | 140 | 6.48 | 0.53 |

Hybrid fibers are added in the SCC mixes by varying volume of cement and the details of hybrid fiber compositions were shown in Table 7.

**Table- 7: Hybrid Fiber Compositions in SCC**

| Hybrid Fiber content | Mix ID | SF (%) | PPF (%) |
|---|---|---|---|
| 0.5 | A | 50 | 50 |
| | B | 25 | 75 |
| | C | 75 | 25 |
| 1.0 | A | 50 | 50 |
| | B | 25 | 75 |
| | C | 75 | 25 |
| 1.5 | A | 50 | 50 |
| | B | 25 | 75 |
| | C | 75 | 25 |
| 2.0 | A | 50 | 50 |
| | B | 25 | 75 |
| | C | 75 | 25 |

From the various workability tests on SCC, with different combinations of hybrid fiber combinations, it was concluded that, the optimum dosage of mix combination was found that HFSCC1.0C (25% SF and 75% PPF).

## III. MECHANICAL STRENGTH PROPERTIES

Mechanical strength properties on FRSCC were examined at varying curing period of 3, 14 and 28 days[8][14]. Table 8 shows the strength properties of concrete mixtures with optimum dosage of fiber content at different curing periods.

**Table- 8: Compressive Strength of FRSCC**

| Mix ID | Average Compressive Strength at different curing period (N/mm$^2$) | | | % Attainment of Strength at varying period | | |
|---|---|---|---|---|---|---|
| | **3** | **14** | **28** | **3** | **14** | **28** |
| **CC** | 16.3 | 38.6 | 43.6 | 40.8 | 96.5 | 109 |
| **SFSCC1.0** | 17.9 | 40.1 | 45.7 | 44.8 | 100 | 114 |
| **PFSCC1.0** | 17.1 | 39.2 | 44.5 | 42.8 | 98 | 111 |
| **HFSCC1.0C** | 19.5 | 43.4 | 47.5 | 48.8 | 109 | 119 |

**Table- 9: Split Tensile and Flexural Strength of FRSCC (N/mm$^2$)**

| Mix ID | Average Split Tensile Strength at different curing period | | | Average Flexural Strength at different curing period | | |
|---|---|---|---|---|---|---|
| | **3** | **14** | **28** | **3** | **14** | **28** |
| **CC** | 2.98 | 3.34 | 3.61 | 2.87 | 3.77 | 4.83 |
| **SFSCC1.0** | 3.01 | 3.94 | 4.04 | 2.99 | 3.88 | 4.98 |
| **PFSCC1.0** | 2.99 | 3.83 | 3.98 | 2.91 | 4.01 | 4.92 |
| **HFSCC1.0C** | 3.56 | 4.21 | 4.48 | 3.56 | 4.21 | 4.97 |

## IV. STRUCTURAL BEHAVIOR OF FRSCC BEAMS

Beam specimens were simply supported over a span of 1500mm and designed to sustain a minimum ultimate load of 30kN [2] [16]. Details of reinforcements present in the test beam are shown in Figure 1. Deflectometers are placed at L/3 distance from either support and at the mid span to determine the deflection of beam under increasing loading conditions. The test setup was shown in Figure 2.

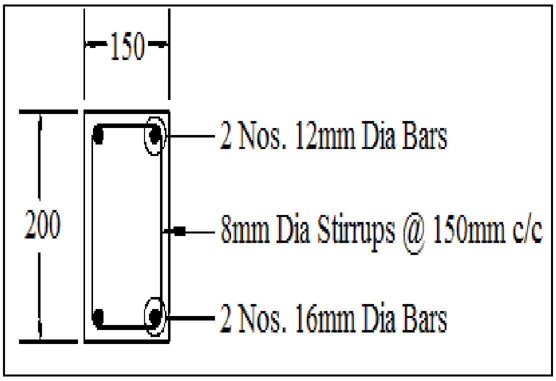

**Fig. 1: Reinforcement Detailing**

a) Before Testing

b) After Testing

**Fig. 2: Experimental Test Setup**

***a. Load vs Deflection Behavior under Static Loading***

Load is applied on the beams through a hydraulic jack of capacity 100kN. For every 2.5 kN loading interval [2] [13], the corresponding mid span deflection readings are noted down and tabulated in Table 10. At the same time, the cracking behavior on the faces for full length of the beam is also observed carefully.

**Table 10: Load vs Deflection details of beams under static loading**

| CC | | SFSCC1.0 | | PFSCC1.0 | | HFSCC1.0 | |
|---|---|---|---|---|---|---|---|
| **D** | **L** | **D** | **L** | **D** | **L** | **D** | **L** |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1.83 | 0 | 2.29 | 0 | 1.64 | 0 | 1.97 |
| 0.07 | 2.89 | 0.10 | 3.81 | 0.04 | 2.45 | 0.06 | 3.63 |
| 0.15 | 4.55 | 0.20 | 5.93 | 0.10 | 3.27 | 0.16 | 5.61 |
| 0.23 | 6.67 | 0.31 | 8.06 | 0.19 | 4.89 | 0.24 | 8.34 |
| 0.32 | 8.52 | 0.41 | 10.00 | 0.27 | 6.62 | 0.35 | 10.18 |
| 0.41 | 9.72 | 0.55 | 11.84 | 0.33 | 8.38 | 0.47 | 11.70 |
| 0.50 | 11.24 | 0.70 | 14.57 | 0.47 | 9.62 | 0.54 | 13.65 |
| 0.58 | 13.19 | 0.83 | 16.23 | 0.58 | 10.82 | 0.64 | 15.17 |
| 0.67 | 14.57 | 0.95 | 17.75 | 0.65 | 12.44 | 0.77 | 16.55 |
| 0.80 | 16.55 | 1.15 | 19.74 | 0.77 | 14.74 | 0.95 | 18.36 |
| 0.92 | 18.21 | 1.30 | 21.86 | 0.91 | 16.50 | 1.10 | 20.34 |
| 1.05 | 20.34 | 1.49 | 24.27 | 1.02 | 18.13 | 1.24 | 22.46 |
| 1.18 | 22.14 | 1.61 | 25.65 | 1.19 | 19.08 | 1.36 | 24.44 |
| 1.32 | 24.27 | 1.76 | 26.85 | 1.33 | 21.90 | 1.49 | 27.03 |
| 1.50 | 27.03 | 1.90 | 28.52 | 1.51 | 23.53 | 1.67 | 29.15 |
| 1.64 | 29.75 | 2.04 | 30.64 | 1.68 | 25.15 | 1.77 | 31.28 |
| 1.80 | 31.56 | 2.21 | 33.22 | 1.87 | 26.78 | 1.90 | 32.48 |
| 1.99 | 33.68 | 2.32 | 35.52 | 2.05 | 28.82 | 2.02 | 33.68 |
| 2.17 | 35.06 | 2.45 | 36.73 | 2.22 | 30.59 | 2.13 | 35.35 |
| 2.38 | 36.27 | 2.57 | 37.65 | 2.41 | 32.46 | 2.21 | 37.93 |
| 2.56 | 37.47 | 2.64 | 39.77 | 2.59 | 33.84 | 2.40 | 39.31 |
| 2.70 | 37.93 | 2.72 | 40.06 | 2.77 | 35.32 | 2.58 | 40.98 |
| 2.88 | 37.65 | 2.88 | 39.60 | 2.91 | 36.52 | 2.72 | 42.50 |
| 3.02 | 36.59 | 3.00 | 39.45 | 3.07 | 37.08 | 2.87 | 44.02 |
| 3.14 | 36.27 | 3.25 | 39.45 | 3.28 | 36.52 | 2.99 | 44.16 |
| 3.29 | 35.98 | 3.52 | 39.45 | 3.47 | 36.41 | 3.36 | 43.56 |
| 3.66 | 35.98 | 3.79 | 39.31 | 3.66 | 36.13 | 3.59 | 43.42 |
| 3.90 | 36.13 | 4.06 | 39.17 | 3.86 | 36.13 | 3.83 | 43.56 |
| - | - | 4.28 | 39.17 | 4.06 | 35.60 | 4.08 | 43.42 |
| - | - | 4.59 | 38.99 | 4.24 | 35.71 | 4.32 | 43.42 |
| - | - | - | - | - | - | 4.80 | 43.24 |

[D – Deflection in mm; L – Load in kN]

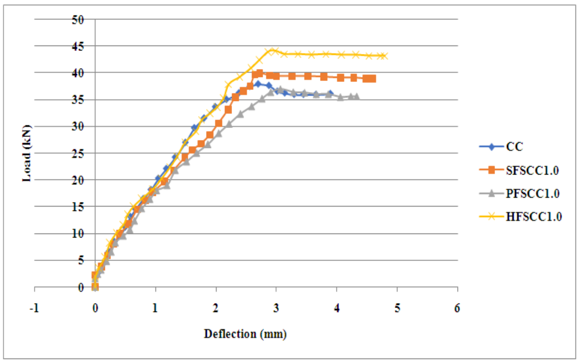

**Fig. 3: Load vs Deflection details of beams under static loading**

**Table -11: Structural Behavior of beams under static loading**

| Mix ID | At First Crack | | At Ultimate | |
|---|---|---|---|---|
| | **Load (kN)** | **Crack width (mm)** | **Load (kN)** | **Deflection (mm)** |
| **CC** | 8 | 0.45 | 37 | 2.6 |
| **SFSCC1.0** | 10 | 0.33 | 38 | 3.0 |
| **PFSCC1.0** | 13 | 0.61 | 40 | 2.7 |
| **HFSCC1.0C** | 16 | 0.84 | 44 | 2.9 |

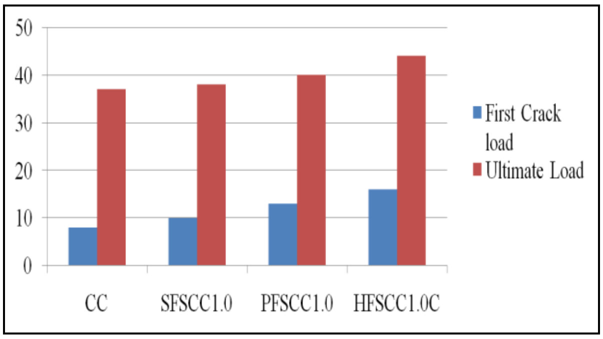

**Fig. 4: Crack behavior of FRSCC under static loading**

### *b. Seismic behavior of FRSCC beams*

When the RCC beams made with FRSCC, beams are tested under static loading conditions and the seismic behavior of RCC beams such as ductility factor and energy absorption capacity were determined and tabulated in Table 12.

Table - 12: Seismic Behavior under static loading

| Mix ID | Ductility Factor | Energy Adsorption |
|---|---|---|
| **CC** | 3.14 | 403 |
| **SFSCC1.0** | 3.18 | 427 |
| **PFSCC1.0** | 3.47 | 526 |
| **HFSCC1.0 C** | 4.104 | 607 |

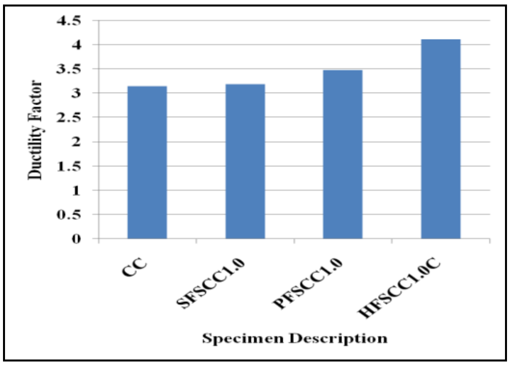

**Fig. 5: Ductility Factor**

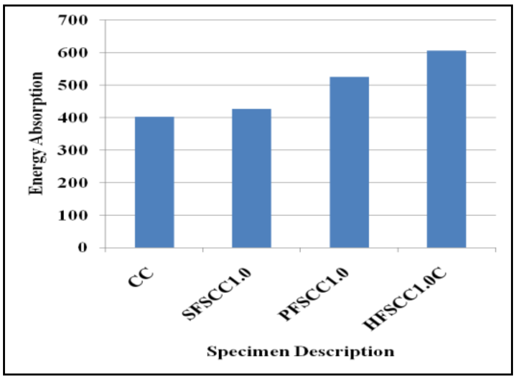

**Fig. 6: Energy Absorption Capacity**

## V.FLEXURAL BEHAVIOR OF RCC BEAMS UNDER CYCLIC LOADING

The RCC beams were applied with cyclic loading through jacks to simulate seismic loading, cyclic loading with a set-up of 5 kN, 10 kN and so on is applied and the sequence of loading is shown in Figure 7.

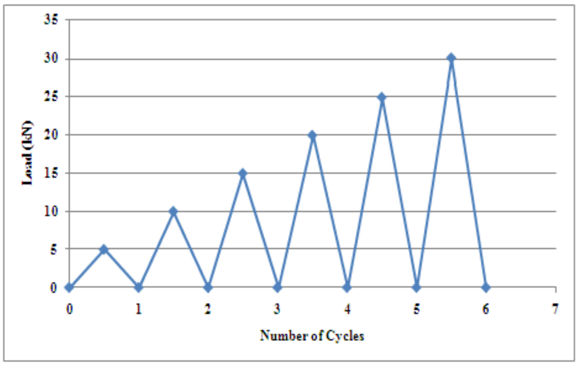

**Fig. 7: Sequence of Cyclic Loading**

When the beam members are subjected to cyclic loading conditions, the beams are tend to bend in the lateral directions. Mid span deflection is measured on the RCC beams made with FRSCC and it is shown in Figure 8 to 11.

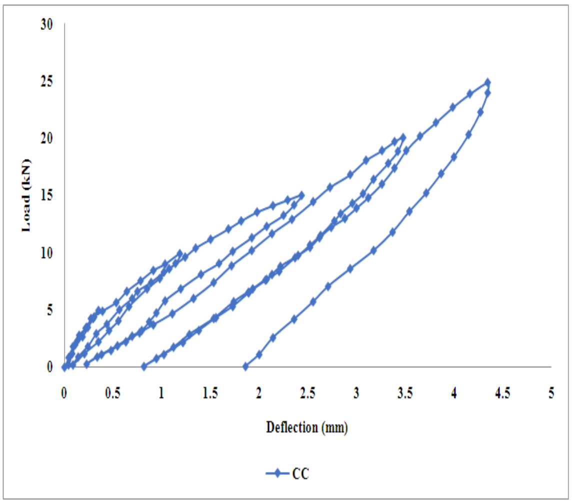

**Fig. 8: Load vs Deflection curve for CC**

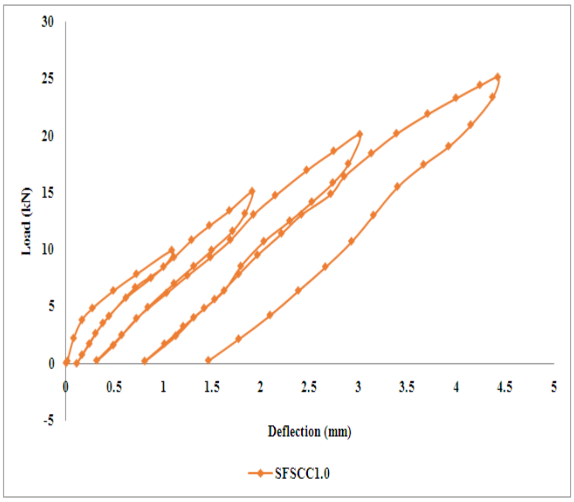

**Fig. 9: Load vs Deflection curve for SFSCC1.0**

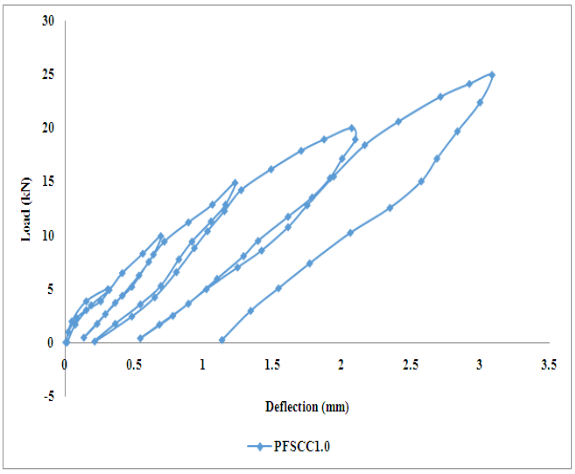

**Fig. 10 :Load vs Deflection curve for PFSCC1.0**

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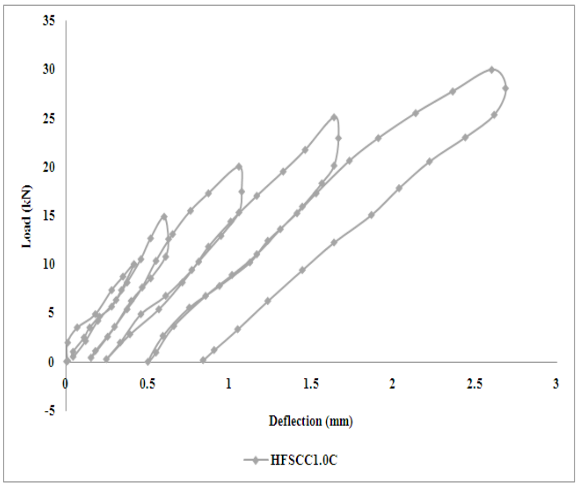

**Fig. 11: Load vs Deflection curve for HFSCC1.0C**

### *a. Seismic behavior of FRSCC beams under cyclic loading*

A tangent is drawn for each cycle of the hysteric curve at load of $P = 0.75P_u$ where $P_u$ is the maximum load of that cycle [5]. The slope of the tangent drawn to each cycle, which gives the stiffness of that cycle, is determined.

**Table - 12: Stiffness Degradation of FRSCC beams under Cyclic Loading**

| No. of Cycles | Stiffness Degradation (kN/mm) | | | |
|---|---|---|---|---|
| | CC | SFSCC1.0 | PFSCC1.0 | HFSCC1.0C |
| 1 | 6.30 | 6.53 | 7.45 | 8.23 |
| 2 | 5.12 | 5.98 | 6.36 | 7.12 |
| 3 | 4.07 | 4.27 | 5.19 | 5.94 |
| 4 | 2.37 | 2.93 | 3.45 | 4.53 |
| 5 | 1.32 | 1.12 | 2.14 | 2.89 |
| 6 | - | - | - | 1.15 |

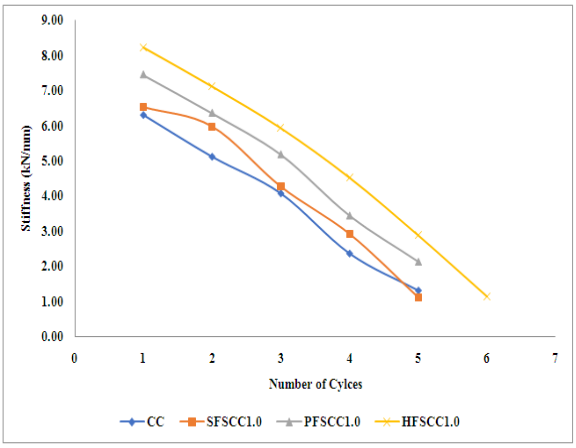

**Fig. 12: Stiffness Degradation of FRSCC beams under Cyclic Loading**

**Table -13: Ductility Factor of FRSCC beams under Cyclic Loading**

| No. of Cycles | Ductility Factor | | | |
|---|---|---|---|---|
| | CC | SFSCC1.0 | PFSCC1.0 | HFSCC1.0C |
| 1 | 1.23 | 1.17 | 1.29 | 0.92 |
| 2 | 4.19 | 4.13 | 3.01 | 1.85 |
| 3 | 8.51 | 7.27 | 5.30 | 2.83 |
| 4 | 12.32 | 11.40 | 8.82 | 5.42 |
| 5 | 15.41 | 16.95 | 13.32 | 8.31 |
| 6 | - | - | - | 12.88 |

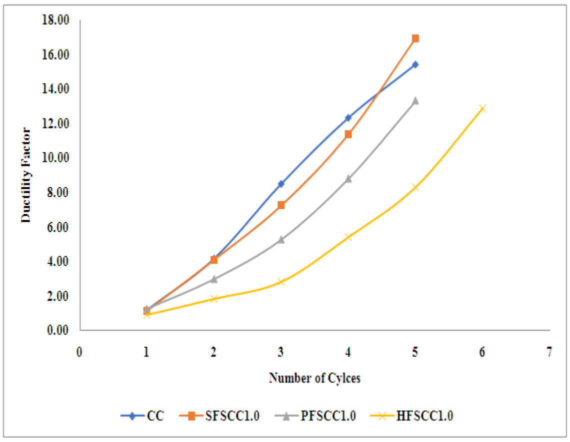

**Fig. 13: Ductility Factor of FRSCC beams under Cyclic Loading**

**Table -14: Energy Absorption Capacity of FRSCC beams under Cyclic Loading**

| No. of Cycles | Energy Absorption Capacity (kNmm) | | | |
|---|---|---|---|---|
| | CC | SFSCC1.0 | PFSC C1.0 | HFSCC1.0C |
| 1 | 5.30 | 5.30 | 6.64 | 5.30 |
| 2 | 15.34 | 5.30 | 17.01 | 22.70 |
| 3 | 55.15 | 15.34 | 53.81 | 87.61 |
| 4 | 165.23 | 103.67 | 178.61 | 221.11 |
| 5 | 259.58 | 211.07 | 316.80 | 375.68 |

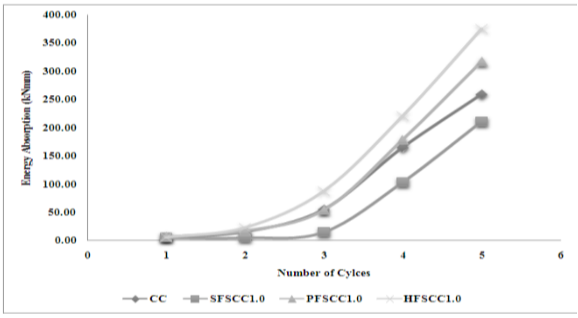

**Fig. 14: Energy Absorption Capacity of FRSCC beams under Cyclic Loading**

## VII. CONCLUSIONS

The following are the results were drawn from the experiments made on FRSCC.

- Self compacting concrete satisfy all the workability tests without adding fibers.
- Volume fraction of 1.0% addition of monofiber, satisfies all the workability requirements of SCC whereas further addition of fibers in the SCC doesn't satisfies the workability requirements. Because the addition of fibers reduces the passing, filling ability and segregation resistance.

- When the fibers are used as a combination of steel and polypropylene fibers, 0.5% and 1.0% addition of hybrid fibers will satisfies the workability tests. And hybrid fiber combination of HFSCC1.0C (25% SF & 75% PPF) was considered as the optimum percentage of volume fraction addition in SCC.
- For beams under static loading the first crack load is delayed for HFSCC1.0C when compared to the other three mixes.
- The load carrying capacity of HFSCC1.0C is 15% higher than the average load carrying capacity of other mix specimens.
- The ductility factor of HFSCC1.0C beam is 4.15 which are higher than the average ductility factor of 3.38 and the energy absorption capacity is improved by 41% from the average value of 485 kNmm.
- The HFSCC1.0C specification beam had delayed first crack load at third cycle of loading indicating the highest load carrying capacity.
- The stiffness degradation has an improved value for HFSCC1.0C than other optimized mixes.
- The cumulative ductility of HFSCC1.0C is improved by around 30% when the average cumulative ductility of four mixes is considered.

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