Computers and Concrete, *Vol. 17, No. 5 (2016) 597-612*
DOI: http://dx.doi.org/10.12989/cac.2016.17.5.597

Self compacting reinforced concrete beams strengthened with natural fiber under cyclic loading

Prasad M.L.V[*1], Prasenjit saha[1] and P.R.Kumar[2]

[1]*Department of Civil Engineering, NIT, Silchar -788010, Cachar District, Assam, India*
[2]*Department of Civil Engineering, National Institute of Technology, Warangal-506004, India*

(Received October 11, 2015, Revised January 21, 2016, Accepted January 25, 2016)

Abstract. The present work focuses on the use of coconut fiber in self compacting concrete. Self-Compacting Concrete (SCC) is a highly flowable, stable concrete which flows readily into place, filling formwork without any consolidation and without undergoing any significant segregation. Use of fibers in SCC bridge the cracks and enhance the performance of concrete by not allowing cracks to propagate. They contribute to an increased energy absorption compared to plain concrete. Coconut fiber has the highest toughness among all natural fibers. It is known that structures in the seismic prone areas are always under the influence of cyclic loading. To justify the importance of strengthening SCC beams with coir fiber, the present work has been undertaken. A comparison is made between cyclic and static loading of coconut fiber reinforced self compacting concrete (FRSCC) members. Using the test data obtained from the experiment, hysteresis loops were drawn and comparison of envelope curve, energy dissipation, stiffness degradation were made and important conclusions were draw to justify the use of coconut fiber in SCC.

Keywords: coconut fiber; self compacting concrete; flexural members; monotonic and cyclic loading

1. Introduction

Self Compacting Concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort, and which is at the same time, cohesive enough to be handled without segregation or bleeding (Okamura and Ozawa 1995 Ouchi, Hibino and Okamura 1996, Okamura and Ouchi 2003, Mahdikhania and Ramezanianpour 2014). SCC has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness (Ouchi *et al.* 1996, H.A.F. 2012).

From pre-historic era, earthquake is regarded as one of the major destructive elements to human beings. It is capable of causing loss of lives, damage to buildings and systems, and interruption of essential services such as electricity, gas, and water supply. In earthquake resistant design, it is important to ensure ductility in the structures, i.e., the structure should be able to deform inelastically and dissipate energy without causing collapse (Naeim and Kelly 1999, Al-

*Corresponding author, Ph.D., E-mail: prasadsmlv@gmail.com, mlv@civil.nits.ac.in

http://www.techno-press.org/?journal=cac&subpage=8 ISSN: 1598-8198 (Print), 1598-818X (Online)

Hammoud *et al*. 2010, Cavojcova *et al*. 2014) Recent earthquakes have demonstrated that even when the beams and columns in a reinforced concrete frame remain intact, the integrity of the whole structure is compromised if the joints, where these members are connected, fail (Kenny 2009; Tang *et al.* 2014). Technologies have been developed to safeguard human life and property from earthquake events (Maghsoudi *et al*. 2006). However, most seismic-resistant solutions are too expensive for the majority of people living in developing countries, particularly in rural parts. An effort has been made in this paper to utilize local natural waste and by product material as supplementary cementing materials to improve the properties of cement concrete. The inclusion of different types of fibers affects the flow characteristics of self compacting concrete (El-Dieb and Taha 2014).

In tropical regions, natural fibers are abundantly available. If utilized properly the cost of construction reduces and also the performance improves. Use of these materials leads to proper disposal of waste, resulting in less impact on environment (Uysal and Yılmaz 2011, Satyanarayana *et al*. 1990). Fly ash and coconut fibers are the materials which have excellent physical and mechanical properties and can be utilized more effectively in the development of composite materials (Sahmaran and Yaman 2007, Ali *et al*. 2012). Concrete being a brittle material fails suddenly under tension and cracks excessively when unreinforced. Steel rebar is conventionally used to reinforce concrete. The present work focuses on the use of coconut fiber in concrete. Fibre reinforced self compacting concrete possesses high flexural and tensile strength, improved ductility, high energy absorption compared to conventional concrete against dynamic loads. Because of these advantages of FRSCC, it can be used in Earthquake resistant structures.

Coconut fiber has the highest toughness among all available fibers (Yan *et al*. 2015). They have potential to be used in low cost concrete structure especially in tropical seismic prone regions (Ali 2014). Tests on concrete specimens under monotonic load were undertaken by earlier researchers and the performance is recognized. However, only few test data is available under cyclic loading. The seismic prone areas are always under the influence of cyclic loading. Hence, to justify the suitability of SCC beams strengthened with coir the project has been undertaken. For this purpose a comparison between cyclic and static loading of coconut fiber reinforced self compacting concrete members need to be well understood.

Some of the studies on the flexure member underlined the effect of bond-slip, shear and flexure including confinement effect under static and fatigue loading were conducted by Altoubat *et al.* 2009, Al-Hammoud *et al*. 2010, Munikrishna *et al*. 2011, Kumar *et al*. 2015) in their study the non-linear performances of RC beam specimens under flexure are evaluated with constant % of Thermo Mechanically Treated (TMT) reinforcement in confined and unconfined conditions by pushover and cyclic loading. The beam specimens under cyclic testing have shown large yield strength but low ductility as compared to pushover testing and concluded that the ductility, which is synonymously used without the relevance either of monotonic or cyclic load of a component or a structure, may result to be lethal if appropriation is neglected in behavior factor in seismic design.

According to Majid Ali *et al*. (2012) study, fibres have the highest toughness amongst natural fibres. They have the potential to be used as reinforcement in low-cost concrete structures, especially in tropical earthquake regions. A comparison between the static and dynamic moduli is conducted. Literature survey showed that tests on concrete specimens using monotonic load was done earlier and its performance was recognized (Yan *et al*. 2015).However, very less data is available under cyclic loading. The proposed research was initiated to observe the change in strength, displacement, ductility, energy dissipation etc due to strengthening by fibers under cyclic loading.

2. Scope of the Investigation

In recent times seismic effects have become a major governing factor in analysis, design and construction. This is mainly due to the occurrence of medium to serve earthquake in regions which were not prone to earthquake earlier (Kenny 2009). Due to this unexpected attack, losses on lives property and infrastructural resources are on the rise particularly in residential areas with majority of non-engineered systems (Farzad and Kelly 1999). Besides improving codal provisions and construction practices, it is necessary to adapt local materials in construction. The application of composite in civil infrastructural activity mostly concentrated on the mechanical strength on composite and not on its usage in structural system (Ali 2012). By considering the requirement here an attempt is made to study the possibilities of using the coconut fiber materials as fiber composite in concrete which not only tries to solve the ductility problem but also the problem of waste disposal (Ali 2014, Munikrishna *et al.* 2011).

In this paper, investigations were carried to know the material characterization as per relevant codes, effect of fiber properties on the performance level of fiber to improve the strength of FRSCC beams, influence of dosage of coconut fibers with respect to varying % addition on the behavior of reinforced concrete (R.C) beams. Also, a point of interest is to know how the stiffness varies with variation in percentage of fiber and Comparison between static loading and cyclic loading of fiber reinforced self compacting concrete (FRSCC) beam in terms of load carrying capacity. In this study mainly focused on load carrying capacity and energy dissipation of beams. A numerical study was carried for evaluating the yield displacement and ultimate load carrying capacity of FRSCC beams. The cumulative energy dissipated is calculated, stiffness values are obtained from hysteresis loop and an envelope curve is drawn.

3. Fiber reinforced self-compacting concrete

The development of SCC marks an important milestone in improving the product quality and efficiency of the building industry. SCC improves the efficiency at the construction sites, enhances the working conditions and the quality and appearance of concrete (Wallevik and Nielsson 2003, Hossain and Lachemi 2006, Dehwah 2012). Use of fibers in SCC bridge the cracks and enhance the performance of concrete by not allowing propagation of cracks (Abiola 2008). They contribute to an increased energy absorption compared with plain concrete (Sahmaran and Yaman 2007, Madandoust *et al*. 2015). FRSCC combines the benefits of SCC in the fresh state and shows an improved performance in the hardened state compared to conventional vibrated concrete due to the addition of the fiber.

Fresh SCC must possess the key properties including filling ability, passing ability and resistance to segregation at required levels. The filling ability is the ability of the SCC to flow into all spaces within the formwork under its own weight. Passing ability is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight. Passing ability is required to guarantee a homogenous distribution of the components of SCC in the vicinity of obstacles (Li and An 2014). The resistance to segregation is the resistance of the components of SCC to migration or separation and remains uniform

Table 1 Mix proportions of SCC with Coconut Fiber

S.No	Desg.	Grade of Concrete	Cement kg	F.A kg	C.A kg	Fly–Ash kg	Coconut Fiber (%)	Water (lit)	S.P (lit)	VMA (lit)
1	SCC 0	M20	276	961	808	150	0	198	3.00	0.20
2	SCC 1		276	961	808	155	1	198	3.33	0.25
3	SCC 2		276	961	808	160	2	198	3.56	0.30
4	SCC 3		276	961	808	165	3	198	3.80	0.35
5	SCC 4		276	961	808	170	4	198	4.00	0.40
6	SCC 5		276	961	808	175	5	198	4.30	0.45

Table 2 Fresh & Hardened properties of SCC with Fiber

		Slump Cone Test		V Funnel Test		L - Box Test			
Sl.No.	Desg.	H-flow Slump (mm)	T_{50} (time in Sec)	Time for complete discharge	T_5 min in Sec	Time for 0-200mm spread	Time for 0-400mm spread d	H_2/H_1	Compressive Strength(Mpa)
1	SCC 1	725	4.00	6.15	8.45	2.45	4.95	0.92	27.64
2	SCC 2	720	4.15	6.80	8.73	2.58	5.21	0.89	27.87
3	SCC 3	720	4.14	7.00	9.20	2.62	5.47	0.88	28.14
4	SCC 4	715	4.20	8.65	10.75	2.65	5.63	0.88	28.28
5	SCC 5	680	4.50	9.72	11..26	3.10	6.34	0.82	28.87
6	SCC 6	640	5.80	12.50	15.48	3.28	6.49	0.75	29.20

throughout the process of transport and placing. EFNARC Specifications (EFNARC. 2005) gives the guidelines for maximum and minimum values of fresh properties.

3.1 Tests on self-compacting concrete

The mix design adopted for SCC and FRSCC specimens was based on Nansu method of mix design (Nan Su, Kung –Chung Hsu.2001) and the mix proportions are shown in Table 1. The slump flow equipment is currently widely used in concrete practice, and the method is very simple and straightforward. The slump flow combined with T50 was selected as the first priority test method for the filling ability of SCC. The V-funnel tests are recommended as second priority alternatives to the T50 measurement. The passing ability of fresh SCC can be tested by L-box & J-

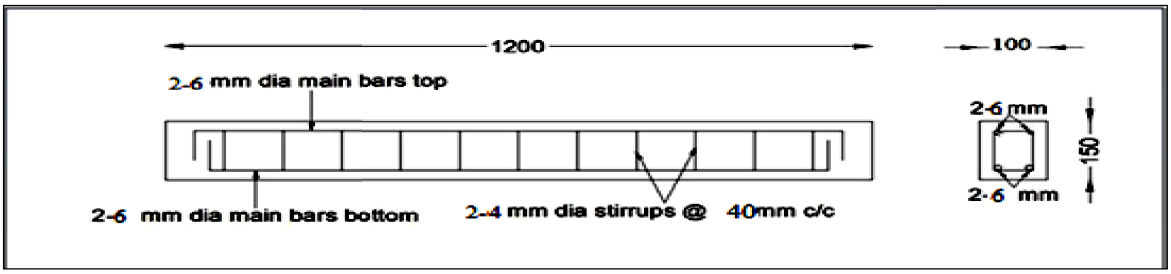

Fig. 1 Steel reinforcement details in beam

Ring. The fresh and of SCC and FRSCC (Table 2) confirm with the EFNARC Specifications (EFNARC 2005) and the compressive strength values are reaching the target strength.

4. Experimental work

4.1 Description of the specimen

In the present study, twelve geometrically similar specimens of size 100 x 150mm were cast and tested. Out of the twelve specimens, two control beams were cast without fibre namely SCC. The remaining ten specimens were cast with coconut fibre with various dosages. The fibre based beams were designated as1-FRSCC, 2-FRSCC, 3-FRSCC, 4-FRSCC, 5-FRSCC. The numerical 1,2,3,4,5 represent the percentage of fibre additions as 1%, 2%, 3%, 4% and 5% respectively of coconut fiber by weight of cement. For each percentage two specimens each were cast and tested. All specimens were designed in such way that the failure occurs in flexure and the provisions of ductile detailing as per IS: 13920 (1993) were taken care.

4.2 Description of the size of beam

The details of a typical beam along with the reinforcement details is shown in Fig 1.The length, width and depth of the beams were 1200 mm, 100mm and 150 mm respectively.

The beam is reinforced with two numbers of 6mm diameter bars placed at bottom as tensile reinforcement. Fe-500(HYSD) steel was used as longitudinal reinforcement. 2 number 6 mm diameter bars are used as main reinforcement at top and bottom as shown in Fig. 1. To hold the reinforcement and to act as shear reinforcement, 2-legged 4mm diameter stirrups (2-4 mm diameter stirrups) were used at 40 mm centre to centre. For shear reinforcement mild steel (Fe-250) was used. Fig.2 shows the details of the beams after casting.

4.3 Materials used

Ordinary Portland cement of grade 43, locally available sand and coarse aggregate was used for all mixtures. Locally available HYSD bars as flexural reinforcement and Mild Steel bars as a stirrup were also used in casting of beams.

4.3.1 Cement

Table 3 Results of tests on cement

S.No.	Name of Test	Details of relevant code	Test Result
1	Consistency	IS :4031 (Part 4)-1988	30%
2	Initial Setting Time	IS : 4031 (Part 5)-1988	35 minutes
3	Final Setting Time	IS : 4031 (Part 5)-1988	5 hrs 30 minutes
4	Specific Gravity	IS : 4031 (Part 11)-1988	3.15
5	Compressive Strength(28 days)	IS : 8112 - 2013	46 Mpa

Table 4 Result of tests on coarse aggregate

S.No.	Name of Test	Details of relevant code	Test Result
1	Aggregate Impact Value	IS : 2386 (Part 4)-1963	14.22%
2	Aggregate Crushing Value	IS : 2386 (Part 4)-1963	21.20%
3	Specific Gravity	IS : 2386 (Part 3)-1963	2.65
4	Fineness Modulus	IS : 2386 (Part 3)-1963	3.62

Table 5 properties of chemical admixture

Chemical admixture	Specific gravity	pH	color	Dosage(l/m^3)	Main component
SP	1.01	6.3	opaque	1 to 4	Polycarboxylic ether
VMA	1.06	6.5	Light yellow	0.5 to 2	Aqueous dispersion of microscopic silica

Table 6 Properties of coir fibre

S.No	Property	Value
1	Diameter(mm)	0.2
2	Density(gm/cm^3)	0.97
3	Natural moisture content (%)	15.85
4	Water absorption (%)	115
5	Tensile strength(Mpa)	215
6	Modulus of elasticity(Gpa)	3.5
7	Elongation at failure (%)	38.0

Ordinary Portland cement conforming to IS 8112-1989 was used for the casting of all specimens. Various test results on cement as per relevant IS codes are tabulated as shown in Table 3. Further, compressive strength test on cement was performed to verify the grade of cement used. The test was performed using the IS: 4031 (Part 6)-1988 procedure.

4.3.2 Coarse aggregate

The nominal size of coarse aggregate used was 20mm. The results of various tests and relevant codes are listed in the Table 4. In the selection of aggregates, the IS: 383 codal Specification for coarse and fine aggregates are followed.

Fig. 2 Details of Cast flexural SCC members with different fiber dosages

4.3.3 Fine aggregate

As per IS: 2386 (Part I)-1963 provision the specific gravity of sand was 2.59. The sieve analysis of sand was carried out as per IS: 2386 (Part I) - 1963. The Fineness Modulus of sand was 2.8. The Fine Aggregate (F.A) used was standard river sand confirming to Zone-II.

4.3.4 Chemical admixtures

A polycarboxylic type superplasticizer (SP) was used in all concrete mixtures. In addition to the SP, a viscosity modifying admixture (VMA) was also used. The properties of both admixtures, as provided by manufacturers, are shown in Table 5.

4.3.5 Fiber

An attempt is made to study the possibilities of reusing the coir fibre materials as fibre composites in concrete which not only tries to solve the ductility problem but also the problem of waste disposal at least to a small extent. Furthermore, it possesses the advantages of a lignocelluloses fiber. The properties of coir fiber are presented in Table 6.

5. Testing of the specimens

A displacement controlled load with a frequency of 0.25 Hz was applied to test specimens. The displacement history applied to all the specimen is shown in Fig. 3. Three cycles of specific amplitude consisting of a push and pull segment repeated before the next increment in displacement was made. The first amplitude applied to all the specimens was ±1mm. The displacement amplitude increment was ±1mm. The experiment was stopped for all specimens at ±8mm in order to maintain similarity among all specimens.

A three point bending test was conducted by applying cyclic loading and monotonic loading. A

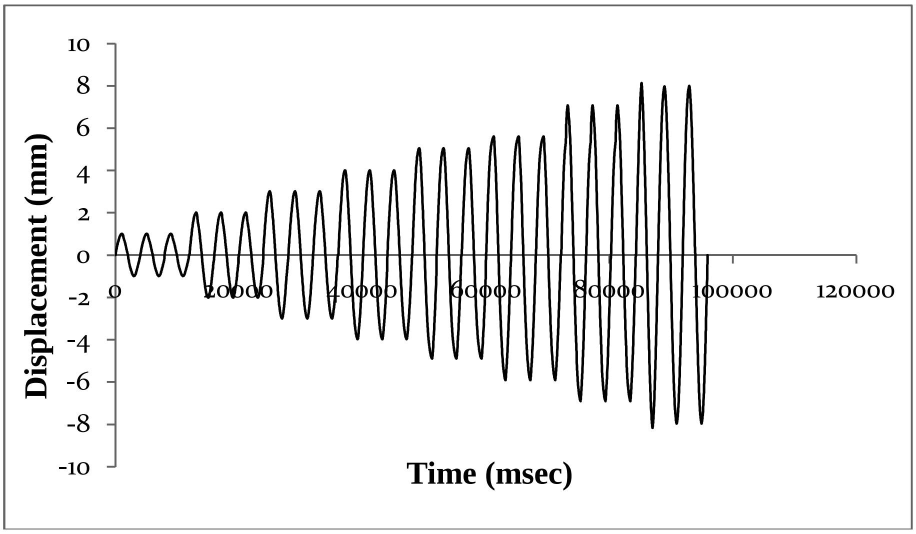

Fig. 3 Typical displacement history applied for all the specimens

Fig. 4(a) Test setup of Reinforced SCC beam

Fig. 4(b) Crack pattern on Reinforced SCC beam

total of six specimens containing different percentages of fiber were tested under cyclic loading, similarly, another six specimens were tested under static loading. A comparison is made between static and dynamic behaviour of reinforced SCC beams to investigate the ultimate load carrying capacity. From dynamic analysis one can determine the hysteresis loop, envelope curve, variation of stiffness and energy dissipation with respect to displacement. A comparison of test results for control SCC specimens with that of FRSCC specimens for different fiber percentage were made in terms of all the above mentioned parameters and conclusions were drawn regarding the benefit of using fiber. Fig. 4 shows the details of test setup and the crack pattern on the reinforced SCC specimens.

5.1 Results of Plain SCC specimen

Many observations have been taken during the experiment and by analysing the hysteresis loop. The first crack appeared in the beam at displacement amplitude of ±2mm. Further, there is an

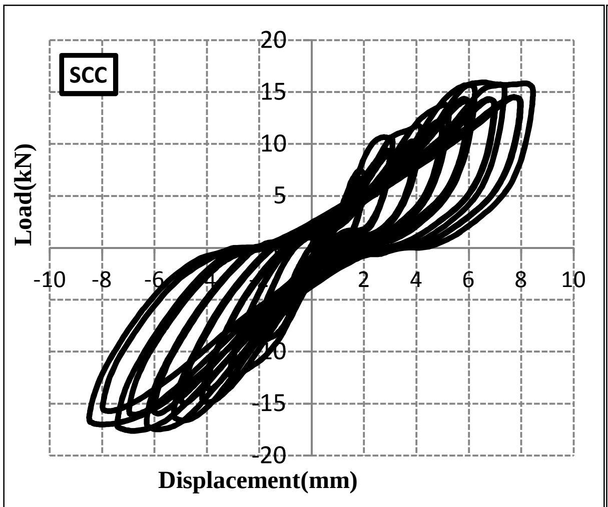

Fig. 5(a) Hysteretic Loop of SCC

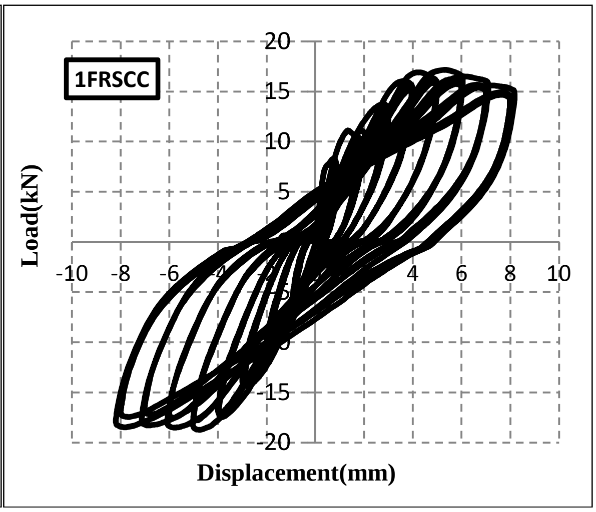

Fig. 5(b) Hysteretic Loop of 1FRSCC

increase in the number of cracks with a gradual increase in the displacement amplitude on the beams. Fig. 5(a) shows the hysteresis loop of SCC specimens. It can be observed from the hysteresis loop that the maximum load carrying capacity of SCC specimen is 15.9 kN in push direction at 20th cycle at a displacement of ±7mm. Similarly, the maximum load is 17.63 kN in the pull direction at 21st cycle at a displacement of ±7mm. The width of the first crack and major cracks have increased gradually. The experiment was stopped at displacement amplitude of ±8mm while the load comes down at desire level. The ultimate load carrying capacity of the specimen was considered as an average of peak load in pull and push direction. It was 16.76 kN for this specimen.

5.2 Results of FRSCC specimen

The displacement controlled load was applied to the specimen and the first crack was appeared at ±2mm. The maximum load carrying capacity of 1-FRSCC specimen in the push direction was 17.14 kN at 17th cycle at a displacement of 6mm and maximum load carrying capacity in the pull direction was 18.72 at 14th cycle at a displacement of ± 5mm as shown in Fig. 5(b). It was observed in this case that a number of cracks were developed on the beam. One major crack was developed and the others were minor cracks. The testing was stopped at displacement of ±8mm to maintain similarities with controlled specimen. Ultimate load carrying capacity was found to be 17.93 kN for this specimen. From the hysteresis loop analysis of 2-FRSCC, it can be observed that the maximum load in push direction was 20.98kN as can be observed in Fig. 5(c). Similarly, the maximum load was observed to be 14.95 kN at 17th cycle at a displacement of 6mm in the pull direction. The width of three major cracks were increased while amplitude increased gradually. In Fig. 4(b), a close view of cracks on beams is shown. The test was stopped at displacement amplitude of ±7mm. The ultimate load capacity of this specimen was 17.9kN. The load of the last cycle displacement in push direction was 18.58 kN and the load of the last cycle displacement in pull direction was 9.39kN respectively. The maximum load carrying capacity of 3-FRSCC specimen is 19.39kN in pull direction at 20th cycle at amplitude of ±7mm. Similarly, the maximum

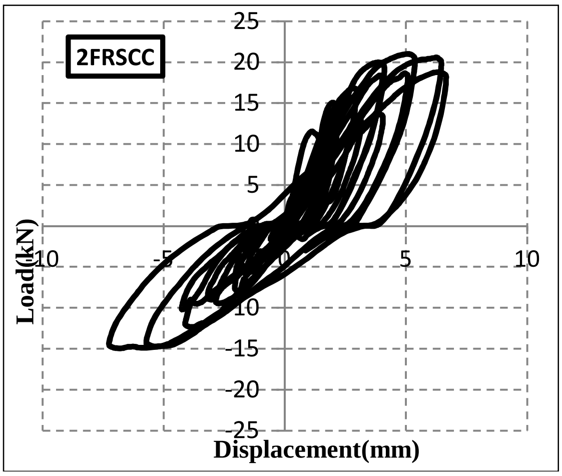

Fig. 5(c) Hysteretic Loop of 2-FRSCC

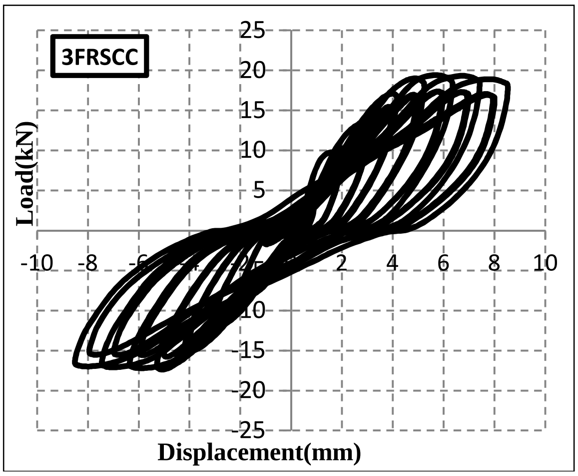

Fig. 5(d) Hysteretic Loop of 3-FRSCC

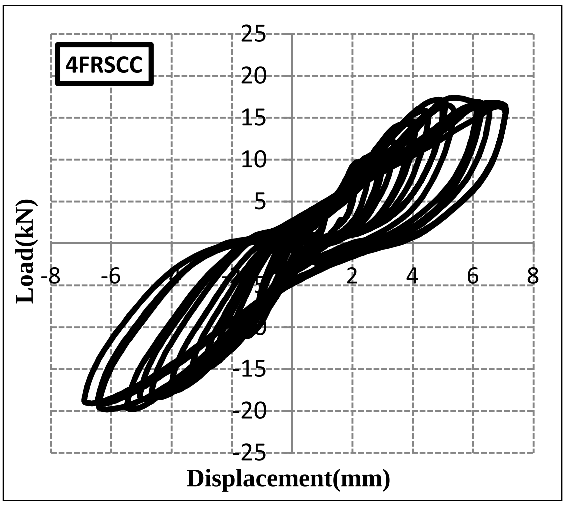

Fig. 5(e) Hysteretic Loop of 4-FRSCC

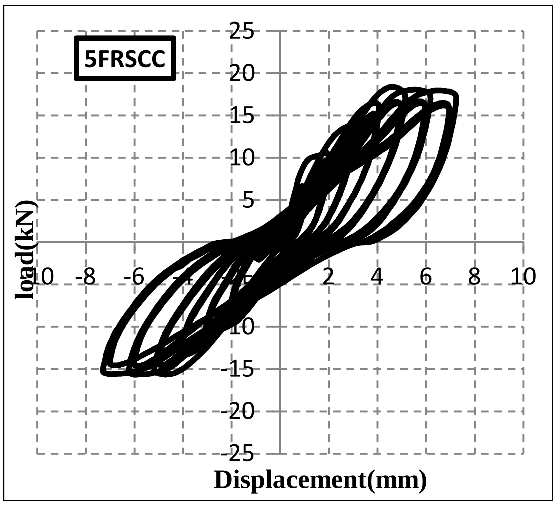

Fig. 5(f) Hysteretic Loop of 5-FRSCC

load of 17.37kN in the pull direction was observed at 14th cycle at a displacement of ±5mm. The load of the last cycle displacement in push and pull direction was 16.99 and 15.54 kN respectively as shown in Fig. 5(d).

The first crack appeared in the 4-FRSCC beam was observed at a displacement of ±3 mm. Further, a number of cracks have increased in the beam with the increase in the incremental displacement. From hysteresis loop analysis it can be observed that the maximum load capacity of 4-FRSCC specimen is 17.36kN in push direction at 15th cycle at amplitude of ±5mm. Similarly, a maximum load in pull direction was observed to be 19.83kN at 18th cycle at a displacement of ±6mm. Fig. 5(e) shows the hysteresis loop and the load of the last cycle displacement in pull and push direction. The load was found to be 16.76 kN and 19.01kN in the pull and push directions respectively. The ultimate load carrying capacity of this specimen was considered as average of peak load in pull and push direction. It was 18.59kN for this specimen. For the 5-FRSCC

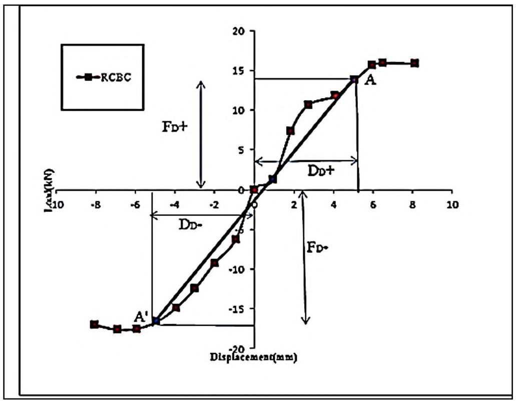

Fig. 6 Determination of secant stiffness envelop

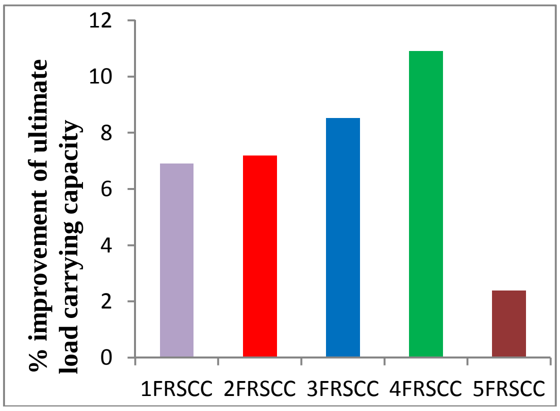

Fig. 7 % improvement in ultimate load due to fiber addition

specimen, the first crack appeared in the beam at an amplitude of ±2mm. Further, many number of cracks have increased in the beam when amplitude was increased gradually. From the hysteresis loop it can be observed that the maximum load capacity of 5-FRSCC specimen is 18.37 kN in push direction at 12^{th} cycle at a displacement of ±6mm, similarly the maximum load of 15.64 in the pull direction is observed at 14^{th} cycle at a displacement of ±5mm. Fig. 5(f) shows the hysteresis loop. The experiment was stopped at a displacement amplitude of ±7mm, while the load came down to the desired level. The load of the last cycle in pull and push direction was 16.48kN and 14.52kN respectively. The ultimate load carrying capacity of this specimen was considered as an average of peak load in push and pull direction. It was 17.02 kN for the specimen 5-FRSCC.

5.3 Discussion on results from cyclic load test

The peak values of load corresponding to the first cycle for each of the displacement amplitude were used to plot envelope curve. The envelope curve reflects nonlinear behaviour of the tested beam as shown in Fig. 6. The secant stiffness corresponding to a specified displacement was considered as stiffness of the assemblage. Two points A and A^1 in positive and negative directions of the envelope curve for a particular amplitude are joined by a straight line. The straight line so obtained by joining both the points is secant to the envelope curve. The slope of this straight line is the stiffness of the joint assemblage corresponding to the particular amplitude and this is calculated by the following expression (Eq. (1)) recommended by (Naeim and Kelly 1999). Fig. 7 shows the percentage improvement in ultimate load due to fiber inclusion under cyclic load test while Fig. 8 shows the same under static load test. Fig. 9 shows the details of plot of stiffness and displacement while Fig. 10 shows the percentage increase in stiffness due to fiber addition.

$$K = \frac{F_D^+ - F_D^-}{D_D^+ - D_D^-} \tag{1}$$

Where D_D^+ and D_D^- in equation are the X ordinate of A and A^1 respectively and F_D^+ and F_D^- are the corresponding Y coordinate in envelope curve Fig. 6. The ability of a structural element to resist an earthquake depends to a large extent on its capacity to dissipate the energy. The area of

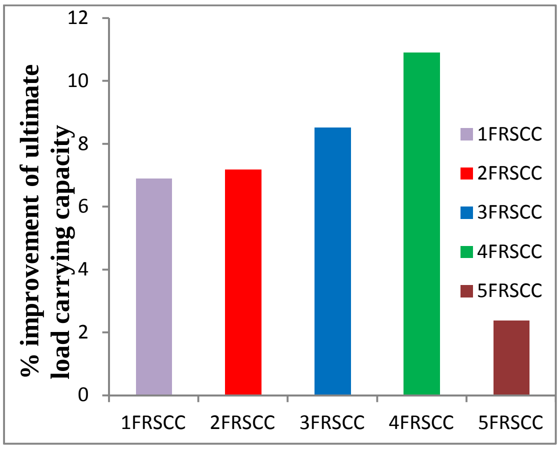

Fig. 8 % improvement of ultimate load under static loading

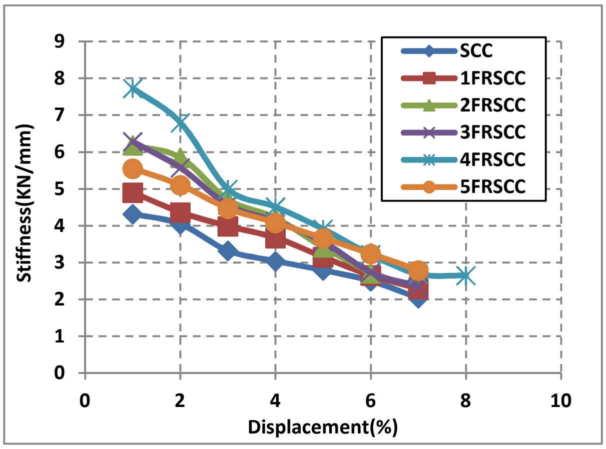

Fig. 9 stiffness vs displacement plot for all specimens

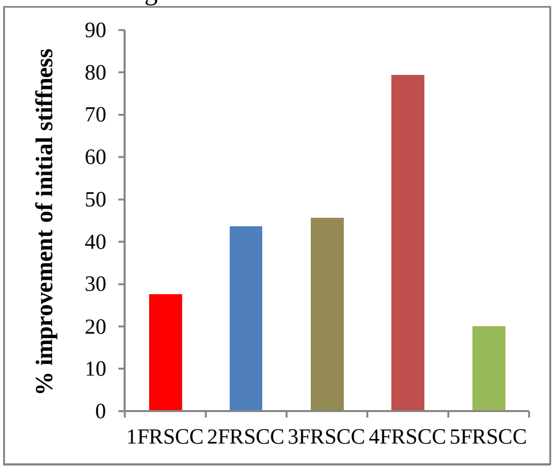

Fig. 10 % improvement in initial stiffness

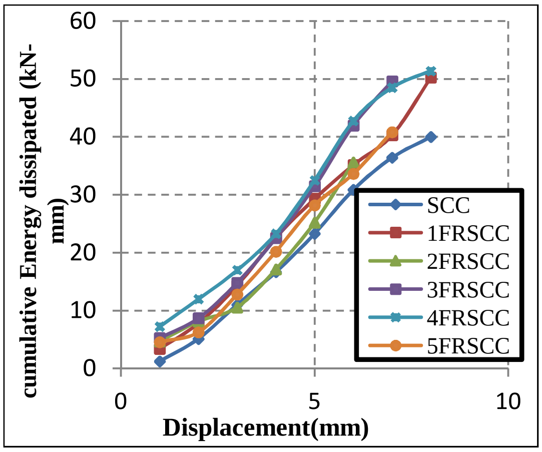

Fig. 11 Cumulative Energy dissipated by all specimens

hysteresis loop is a measure of the energy dissipated. The cumulative energy dissipated at particular amplitude was calculated by summing up the energy dissipated in all the preceding cycles including that amplitude (Fig. 11).

5.4 Comparison of test results of Plain SCC and FRSCC specimens

The envelope curve of load versus displacement for control as well as fibrous specimens is shown in Fig. 12. It can be observed that the curves corresponding to fibrous specimens shows higher load carrying capacity than the control specimen. There is a gain in cumulative energy dissipation at failure stage due to fibre. The percentage gain in ultimate load carrying capacity of FRSCC specimen due to inclusion of fibers and the initial stiffness of the fibrous specimens are shown in Table 7. The percentage gain in the initial stiffness of the specimens with fiber is shown in Table 7.

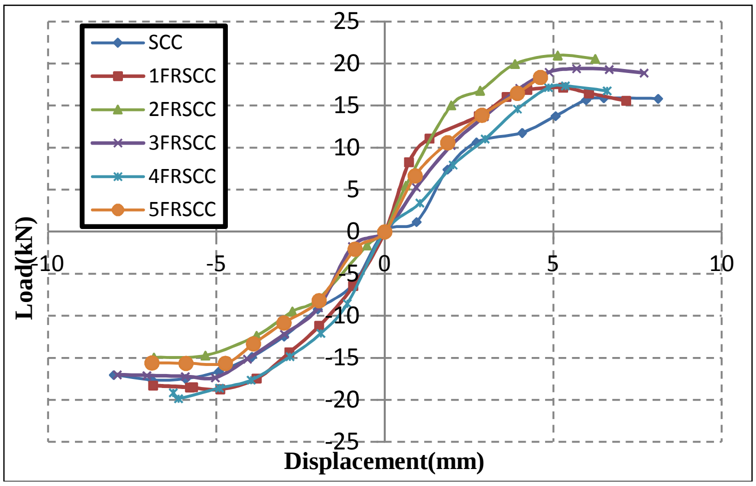

Fig. 12 Envelopes of hysteresis loops for SCC & FRSCC

Table 7 FRSCC specimens gain in ultimate load and initial stiffness

S.No	Specimen	% Gain in ultimate load carrying capacity	Initial stiffness of strengthened (kn/mm)	% Gain in stiffness
01	1-FRSCC	6.94	5.5	27.61
02	2-FRSCC	7.24	6.19	43.00
03	3-FRSCC	8.44	6.28	45.70
04	4-FRSCC	10.91	7.73	79.35
05	5-FRSCC	2.38	5.20	20.00

5.5 Testing of specimen under static loading

In monotonic loading six specimens of different percentage of fibre including one control specimen were tested. Three point bending test was conducted by applying monotonic loading. From static loading the ultimate load carrying capacity of the specimen was evaluated. The load displacement graph is shown in Fig. 13. The experiment was stopped at failure of the specimen. It was found that the ultimate load carrying capacity was 30.8kN at a displacement of around 15.75 mm for the specimen designated as 3-FRSCC. It gives the best result out of all beams. From the analysis of static loading it was found that after an increment of 3 percent of fibre the capacity of the beam reduces. The load carrying capacity of SCC or control specimen was at a displacement of around 17.3mm.

5.6 Interpretation of result

After analysis of all the specimens it can be observed from the results that there is an enhancement in the behaviour of fibrous SCC specimens. The envelope curves of hysteresis loop of all specimens are shown is shown in Fig. 12. It can be observed that the envelope curve for 4-FRSCC specimen shows improvement in ultimate load carrying capacity. The ultimate load carrying capacity of 4-FRSCC specimen is the highest, when cyclic load is applied and

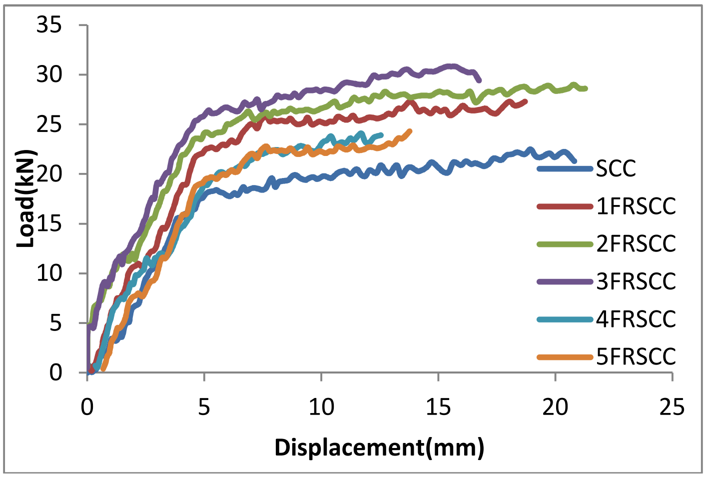

Fig. 13 Load deflection curve of control specimen

improvement percentage of ultimate load carrying capacity is 10.91%. In case of static loading, the improvement in the percentage of ultimate load carrying capacity is 38.7% for 3-FRSCC. It can be noted that after a certain limit of percentage of fibre that is 4%, there is a decrease in the strength. This can be attributed to non-uniform distribution of fibre in the SCC. Fibers improve the initial stiffness by 79.35% for 4-FRSCC specimen. It can be noted that in the specimen 4-FRSCC there is an improvement in the energy dissipation among all the specimens. This was 23.07% for 4-FRSCC specimen.

6. Conclusions

Based on the experiments conducted and interpretation of result the following major conclusions can be drawn

• The addition of fibers plays an important role for arresting, delaying and propagating of cracks in the flexural members.

• There was an increase in the load carrying capacity due to addition of fibers (ranging from 6.9% to 10.91%) in cyclic loading.

• There was a remarkable increase in load carrying capacity due to addition of fiber (ranging from 22.97% to 38.7%) in monotonic loading.

• There is a good increase in the initial stiffness in fibrous SCC specimens (ranging from 27% to 79%).

• The optimum percentage of coconut fiber was found to be 4%, beyond which engineering properties of SCC were not satisfied.

• All the beams strengthened with Coconut Fibers experienced ductile flexural failures and none of the beams exhibited premature brittle failure.

References

Al-Hammoud, R., Soudki, K. and Topper, T.H. (2010), "Bond analysis of corroded reinforced concrete beams under monotonic and fatigue loads", *Cement Concrete Compos.*, **32**(3), 194-203.

Ali, M. (2014), "Seismic performance of coconut-fibre-reinforced-concrete columns with different reinforcement configurations of coconut-fibre ropes", *Constr. Build. Mater.*, **70**, 226-230.

Ali, M., Liu, A., Sou, H. and Chouw, N. (2012), "Mechanical and dynamic properties of coconut fibre reinforced concrete", *Constr. Build. Mater.*, **30**, 814-825.

Altoubat, S., Yazdanbakhsh, A. and Rieder, K.A. (2009), "Shear behavior of macro-synthetic fiber-reinforced concrete beams without stirrups", *ACI Mater. J.*, **106**(4), 381-389.

Čavojcová, A., Moravčík, M., Bahleda, F. and Jošt, J. (2014), "Experimental verification of reinforced concrete member under cyclic loading", *Procedia Eng.*, **91**, 262-267.

Dadi, V.S.K. and Agarwal, P. (2015), "Comparative post-yield performance evaluation of flexural members under monotonic and cyclic loadings based on experimental tests", *Struct.*, **2**, 72-80.

Dehwah, H.A.F. (2012), "Mechanical properties of self-compacting concrete incorporating quarry dust powder, silica fume or fly ash", *Constr. Build. Mater.*, **26**(1), 547-551.

EFNARC (2005), "Specifications and guidelines for self-compacting concrete", *European Federation of Producers and Applicators of Specialist Products for Structures*, Association House, 99 West Street, Farnham, United Kingdom, February.

El-Dieb, A.S. and Taha, M.R. (2012), "Flow characteristics and acceptance criteria of fiber-reinforced self-compacted concrete (FR-SCC)", *Constr. Build. Mater.*, **27**(1), 585-596.

Hossain, K.M.A. and Lachemi, M. (2006), "Time dependent equations for the compressive strength of self-consolidating concrete through statistical optimization", *Comput. Concrete*, **3**(4), 249-260.

Indian Standard Code IS: 2386-1997 (2002), "Methods of test for aggregates for concrete", reprinted, *Bureau of Indian Standards*, New Delhi, India.

Indian Standard Code IS: 383-1970 (2002), "Specification for coarse and fine aggregates from natural sources for concrete", *Bureau of Indian Standards*, New Delhi, India.

Indian Standard Code IS: 8112-2013 (2013), "Specifications for 43 grade ordinary Portland cement", *Bureau of Indian Standards*, New Delhi, India.

IS 13920-1993 (2003), "Ductile detailing of reinforced concrete structures subjected to seismic forces-code of practice", *Bureau of Indian Standard*, New Delhi, India.

Kenny, C. (2009), "Why do people die in earthquakes? The costs, benefits and institutions of disaster risk reduction in developing countries", *The Costs, Benefits and Institutions of Disaster Risk Reduction in Developing Countries*, World Bank Policy Research Working Paper Series.

Lertwattanaruk, P. and Suntijitto, A. (2015), "Properties of natural fiber cement materials containing coconut coir and oil palm fibers for residential building applications", *Constr. Build. Mater.*, **94**, 664-669.

Li, S. and An, X. (2014), "Method for estimating workability of self-compacting concrete using mixing process images", *Comput. Concrete*, **13**(6), 781-798.

Madandoust, R., Ranjbar, M.M., Ghavidel, R. and Shahabi, S.F. (2015), "Assessment of factors influencing mechanical properties of steel fiber reinforced self-compacting concrete", *Mater. Des.*, **83**, 284-294.

Maghsoudi, A.A. and Bengar, H.A. (2006), "Flexural ductility of HSC members", *Struct. Eng. Mech.*, **24**(2), 195-212.

Mahdikhani, M. and Ramezanianpour, A.A. (2014), "Mechanical properties and durability of self consolidating cementitious materials incorporating nano silica and silica fume", *Comput. Concrete*, **14**(2), 175-191.

Munikrishna, A., Hosny, A., Rizkalla, S. and Zia, P. (2011), "Behavior of concrete beams reinforced with ASTM A1035 grade 100 stirrups under shear", *ACI Struct. J.*, **108**(1), 34.

Naeim, F. and Kelly, J.M. (1999), *Design of seismic isolated structures: from theory to practice*, John Wiley & Sons.

Okamura, H. and Ouchi, M. (2003), "Self-compacting concrete", *J. Adv. Concrete Tech.*, **1**(1), 5-15.

Okamura, H. and Ozawa, K. (1995), "Mix design for self-compacting", *Concrete library of JSCE*, 107-120.

Ouchi, M., Hibino, M. and Okamura, H. (1997), "Effect of superplasticizer on self-compactability of fresh concrete", *J. Transp. Res. Board*, **1574**, 37-40.

Producers and Applicators of Specialist Products for Structures, Association House, 99 West Street, Farnham, United Kingdom, February 2005.

Sahmaran, M. and Yaman, I.O. (2007), “Hybrid fiber reinforced self-compacting concrete with a high-volume coarse fly ash”, *Constr. Build. Mater.*, **21**(1), 150-156.

Satyanarayana, K.G., Sukumaran, K., Mukherjee, P.S., Pavithran, C. and Pillai, S.G.K. (1990), “Natural fibre-polymer composites”, *Cement Concrete Compos.*, **12**(2), 117-136.

Su, N., Hsu, K.C. and Chai, H.W. (2001), “A simple mix design method for self-compacting concrete”, *Cement Concrete Res.*, **31**(12), 1799-1807.

Tang, Z., Ali, M. and Chouw, N. (2014), “Residual compressive and shear strengths of novel coconut-fibre-reinforced-concrete interlocking blocks”, *Constr. Build. Mater.*, **66**, 533-540.

Uysal, M. and Yilmaz, K. (2011), “Effect of mineral admixtures on properties of self-compacting concrete”, *Cement Concrete Compos.*, **33**(7), 771-776.

Waifielate, A.A. and Abiola, B.O. (2008), “Mechanical property evaluation of coconut fibre”, Master's Degree Thesis, Department of Mechanical Engineering Blekinge Institute of Technology, Sweden.

Wallevik, O. and Nielsson, I. (2003), “Self-compacting concrete”, *3rd International RILEM Symposium on Self-Compacting Concrete*.

Yan, L., Su, S. and Chouw, N. (2015), “Microstructure, flexural properties and durability of coir fibre reinforced concrete beams externally strengthened with flax FRP composites”, *Compos. Part B: Eng.*, **80**, 343-354.

CC