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FLEXURAL BEHAVIOR OF STEEL-FIBER-ADDED-RC (SFARC) BEAMS WITH C30 AND C50 CLASSES OF CONCRETE

Hamid Pesaran Behbahani[1], Behzad Nematollahi*[2], Abdul Rahman Mohd. Sam[3], F. C. Lai[4]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Malaysia
[2]Civil Engineering Department, Universiti Putra Malaysia (UPM), Serdang, Malaysia
[3]Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Malaysia
[4]Regional Technology Support Centre, Sika Kimia Sdn Bhd, Malaysia

*Corresponding E-mail : behcom62@gmail.com

ABSTRACT

Although conventional reinforced concrete (RC) is the most globally used building material; however, its detrimental structural characteristics such as brittle failure mechanism in tension need to be improved. Discrete and short steel fibers (SFs) can be added into the concrete mix to improve its brittleness. The effects of the addition of optimum percentage of SFs on flexural behavior of RC beams have been investigated in this paper. In this study, the optimum percentage of hooked-end SFs with the dimensions of 0.75 mm in diameter and 50 mm in length are added in RC beams with two different classes of concrete (i.e. two different compressive strengths of 30MPa (C30) and 50MPa (C50)). In order to determine the optimum percentage of SFs added to the concrete mix, 15 prisms and 30 cubes with 5 different percentages of SFs (i.e. 0%v/v, 0.5%v/v, 1%v/v, 1.5%v/v, and 2%v/v) from both C30 and C50 classes of concrete have been tested. Based on the results of the flexural strength and compressive strength tests, it is found that the optimum value is 1% by volume (i.e. 78.5 kg/m^3) for the specific type of fiber used in this study. Subsequently, to investigate the flexural behavior of steel fiber added RC (SFARC) beams compared to conventional RC beams with no SFs, two RC beams with the dimensions of 170 mm in height, 120 mm in width, and 2400 mm in length, with the SF percentages of 0 and 1%v/v and both having exactly the same steel reinforcement were tested under flexure using a four-point loading test setup for both C30 and C50 classes of concrete. The experimental results show that the SFARC beams with 1% by volume of the SFs have higher first cracking strength, ultimate flexural strength, stiffness, and ductility compared to that of the conventional RC beams with no SFs. Furthermore, the addition of the SFs has more effects on the RC beams with higher compressive strength (50 MPa) compared to lower concrete grade (30 MPa).

Keywords: *Optimum steel fiber percentage, Steel fiber added reinforced concrete (SFARC) beam, Flexural behavior*

1.0 INTRODUCTION

Structural concrete is by far one of the most extensively used construction material all over the world. Concrete is a brittle material, with little capacity to resist tensile stresses/strains without cracking. Thus it requires reinforcement before it can be used as construction material. Historically, this reinforcement has been in the form of continuous reinforcing bars which could be placed in the structure at the appropriate locations to withstand the imposed tensile and shear stresses. Fibers, on the other hand, are generally short, discontinuous, and randomly distributed throughout the concrete to produce a composite construction material known as fiber reinforced concrete (FRC). Steel fiber (SF) is the most popular type of fiber used in reinforced concrete.

Fibers are used to prevent/control plastic and drying shrinkage in concrete and significantly increase its flexural toughness, the energy absorption capacity, ductile behaviour prior to the ultimate failure, reduces cracking, and improves durability [1]. Steel fiber reinforced concrete

(SFRC) also known as steel-fiber-added concrete (SFAC) has extensive applications such as tunnel linings, large slabs and floors with great live load, rock slope stabilization, dam constructions, composite metal decks, seismic retrofitting, repairs and rehabilitations of marine structures, fire protection coatings, concrete pipes as well as conventional RC frames due to its superior toughness against dynamic loads compared to conventional reinforced concrete [1, 2]. The objectives of this study are as follows:

1) To determine the optimum percentage of the specific type of SFs used in this study for C30 and C50 classes of concrete based on the cube compressive strength and flexural strength tests with five different SF dosages of 0%v/v, 0.5%v/v, 1%v/v, 1.5%v/v, and 2%v/v.
2) To determine the structural flexural behaviour of steel-fiber-added reinforced concrete (SFARC) beams of C30 and C50 classes of concrete, containing the optimum percentage of the SFs as determined in the previous step, compared against the conventional RC beams of the same concrete grades.

2.0 BACKGROUND OF STUDY

Hannant [3] found that the addition of steel fibers has more influence on the flexural strength of concrete compared to its tensile/compressive strength. As reported by Oh et al. [4], the flexural strength of SFRC has been increased about 55% with the addition of 2% by volume of steel fibers. Johnston [5, 6] has found that the compressive strength of SFRC is increased about 20% with the addition of 1.2% by volume of steel fibers. Research conducted by Johnston [7] showed that the compressive strength of SFRC has been increased from 0 to 15% with the addition of up to 1.5% of steel fibers by volume. In a research conducted by Hartman [8] twelve different SFRC beams containing two different SFs amount of 60 and 100 kg/m^3 of Dramix RC-65/35-BN type were tested and it was concluded that the ratio of the experimental ultimate load to the theoritical ultimate load was bigger for those SFRC beams having a 60 kg/m^3 amount of SFs. Narayanan and Darwish [9] reported that the mode of failure has changed from shear to flexure when the percentage of steel fibers was increased beyond 1.0%.

According to the literature, it can be understood that the optimum percentage of SFs in SFARC beams should be within the range of 1 to 2.5% by concrete volume and depends on the type of the fiber (i.e its aspect ratio) and properties of the fresh concrete such as workability and its maximum size aggregates. The addition of less than 1% by voulme of SFs is inadequate and amounts beyond 2.5% is also ineffective mostly due to the inadequate compaction and localized distribution of the fibers in the concrete mix leading to a considerable reduction in the compressive strength compared with the same grade of concrete [1].

To the best of our knowledge, there is only one extensive research regarding the optimum percentage of SF for SFARC beams and the economic study for the usage of SFs in conventional RC beams conducted by Altun et al. [1]. All the previous research is conducted with only one grade of concrete, and the effects of SFs on different classes of concrete and the type of fibers have not been considered. The flexural behaviour and toughness of conventional RC and SFARC beams for C20 and C30 classes of concrete with three different SF dosages of 0, 30, 60 kg/m^3 have been investigated in their study in a comparative way. It was concluded that both the ultimate loads and the flexural toughness of SFARC beams manufactured with concrete grades of 20 MPa and 30MPa with 30 kg/m^3 of SFs increased significantly compared to those conventional RC beams and the addition of 30 kg/m^3 of steel fibers is better than that of 60 kg/m^3 for the SFARC beams.

3.0 EXPERIMENTAL WORK

3.1. MATERIALS AND MIX PROPORTIONING

Two concrete grades of 30 and 50MPa were used in this study. The mix design was based on the guidelines given in the Design of Normal Concrete Mixes [10] with slightly modification to adapt to the available local raw materials. To achieve concrete grade of 50 MPa water cement ratio has been reduced from 0.56 to 0.4 by using the superplasticizer. The concrete mix design used in this study is shown in Table 1. The steel fibers used in this study are of Wirand® Fiber-FF3 type with a diameter of 0.75 mm and a length of 50 mm as shown in Figure 1, and its strain at failure and tensile strength are less than 4% and beyond 1100 MPa, respectively.

To ensure that the SFs have been distributed uniformly in the concrete matrix, the rate of SFs addition into the concrete mixer was 20 kg/min, and then the mixer has rotated at high speed for 5 minutes, as recommended by the relevant RILEM publications [11, 12].

Table 1: Mix Proportioning of the Concrete with Grades of 30 and 50

Ingridients	Mass (kg/m^3)	
	Grade 30 MPa	Grade 50 MPa
W/C Ratio	0.56	0.4
Mixed Water	230	164
Portland Cement	410	410
Fine Aggregate (Sand)	902	780
Coarese Aggregate (Max size = 16 mm)	833	1040
Superplasticizer	0	1.4 Liter/100 kg of cement

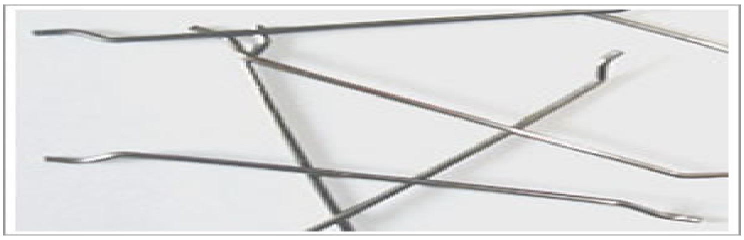


Figure 1: Hooked-end shape steel fibers used in this Study

3.2. OPTIMUM PERCENTAGE OF SFS IN C30 AND C50 CLASSES OF CONCRETE

To determine the optimum percentage of SF for C30 and C50 classes of concrete, cube compressive strength and flexural strength tests with five different SF dosages of (0%, 0.5%, 1%, 1.5%, 2%)v/v were carried out. Vebe time test was carried out to determine workability of the mix designs.

3.2.1.CUBE COMPRESSIVE STRENGTH TEST

The compressive strength of the specimens at the age of 28 days was measured in a test setup in accordance with BS 1881: Part 116 [13]. For each concrete grade of 30 MPa and 50 MPa, thirty cubic specimens with the dimensions of 150 × 150 × 150 mm were prepared. Six cubic specimens for each of the 5 different SF dosages of (0%, 0.5%, 1.0%, 1.5%, and 2%) v/v were cast. A hand poker vibrator was used for compaction of concrete in cubic specimens. All 60 cubes were de-moulded after one day and immersed in a water tank for a period of 28 days to assure adequate curing.

3.2.2.FLEXURAL STRENGTH TEST

The flexural strength test was conducted in accordance with ASTM C1018-97 [14]. For each of the different SF dosages of (0%, 0.5%, 1.0%, 1.5%, and 2%)v/v, three prisms with the dimensions of 150 × 150 × 750 mm for each of the C30 and C50 classes of concrete were prepared. A hand poker vibrator was used for compaction of concrete in prisms. All 30 prisms were de-moulded after one day and immersed in the water tank for a period of 28 days to assure adequate curing. After 28 days, each prism was tested under flexure using the four point loading test setup. The specifications of the cubes and prisms used to determine the optimum percentage of the SFs in C30 and C50 classes of concrete are summarized in Table 2.

Table 2: characteristics of the cubic and prism specimens used in this study

Volumetric ratio of the SF	Classes of concrete	Number of specimens	
		Cubes (150 ×150 × 150 mm)	Prisms (150 × 150 × 750 mm)
0	C30-0.0%	6	3
	C50-0.0%	6	3
0.5	C30-0.5%	6	3
	C50-0.5%	6	3
1	C30-1.0%	6	3
	C50-1.0%	6	3
1.5	C30-1.5%	6	3
	C50-1.5%	6	3
2	C30-2.0%	6	3
	C50-2.0%	6	3

3.2.3.VEBE TIME TEST

Vebe time test was used to measure the workability of the concrete mix in this study. The Vebe time test determines the remoulding ability of concrete under vibration. The test results reflect the time required to remould an amount of concrete under given vibration situation.

3.3. STRUCTURAL FLEXURAL BEHAVIOR OF SFARC BEAMS

For each concrete grade of 30 and 50 MPa, two beams with the dimensions of 120 × 170 × 2400 mm were cast with the optimum percentage of SFs, as determined in the previous tests, added to one of the beams of each concrete grade to prepare the SFARC beams with two different classes of concrete. The other beam of each grade was cast as conventional RC beams with no SFs. The dimensions, concrete mix, and the steel reinforcement used in both beams of each grade were all exactly the same and the only difference was the addition of the optimum SF dosage in one of the beams. The beam’s reinforcement inside wooden moulds before casting is shown in Figure 2. Figure 3 shows the cross section of the RC and the SFARC beams used in this study. As shown in this figure, two steel bars with the diameter of 12 mm and characteristic yield strength of 460 N/mm^2 were used in bottom of the section and two hanger bars with the diameter of 6 mm and characteristic yield strength of 250 N/mm^2 were used at the top. The shear links with a diameter of 6 mm and characteristic yield strength of 250 N/mm^2 were arranged at 100 mm centre to centre. The specifications of the RC and the SFARC beams tested are summarized in Table 3. Proper supports for the wooden moulds were provided to prevent mould deformation during vibration and compaction process. All the four beams were de-moulded after one day and kept completely covered by burlap. Regularly all the beams were splashed with lots of water while covered up under burlap for a period of 28 days. All the four beams were tested at the age of 28 days in a four-point loading test setup as shown in Figure 4. As shown in this figure, the beam was positioned as simply supported. The load was transmitted to the beam through a hydraulic jack placed at the centre of the spreader beam and measured by the load cell located between the spreader beam and the hydraulic jack. Three linear variable differential transducers (LVDTs) were installed using a magnetic stand at the soffit of the beam in the mid-span as well as the two points where the loads were acted. The LVDTs and the load cell were connected to a data logger. The beams were loaded to failure. The rate of load increase was 0.5 kN (i.e. for every 0.5 kN increase in load, corresponding deflection were measured through the LVDTs. Figure 5 shows a picture taken from the test setup used in this study.

Figure 2: Appearance of the RC and the SFARC beams before casting

Table 3: Specifications of the RC and the SFARC beams used in this study

Beam type	No. of beam specimens (120 × 170 × 2400 mm)	
	C30	C50
RC	1	1
SFARC with Opt. percentage of SFs	1	1

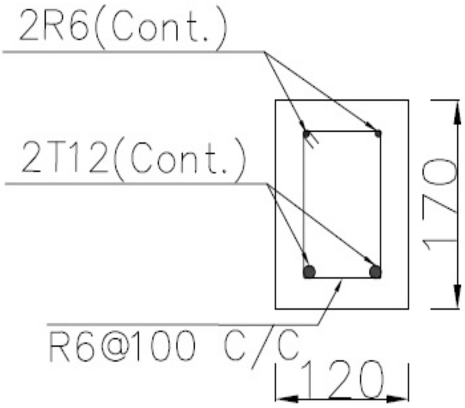


Figure 3: Cross Section of the RC and the SFARC Beams (dimensions in mm)

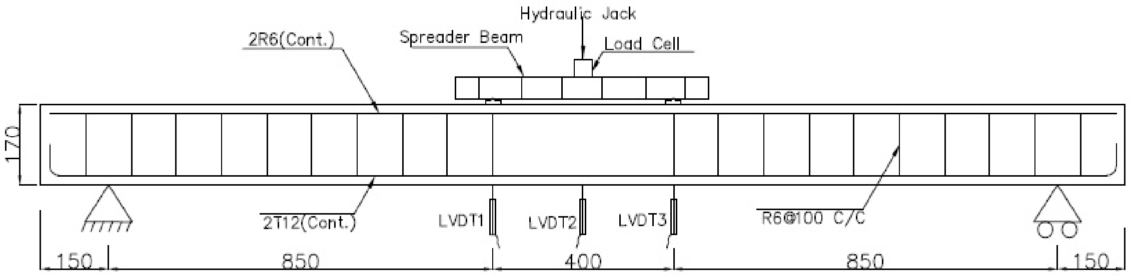


Figure 4: Schematic four-point loading test setup used in this study (dimensions in mm)

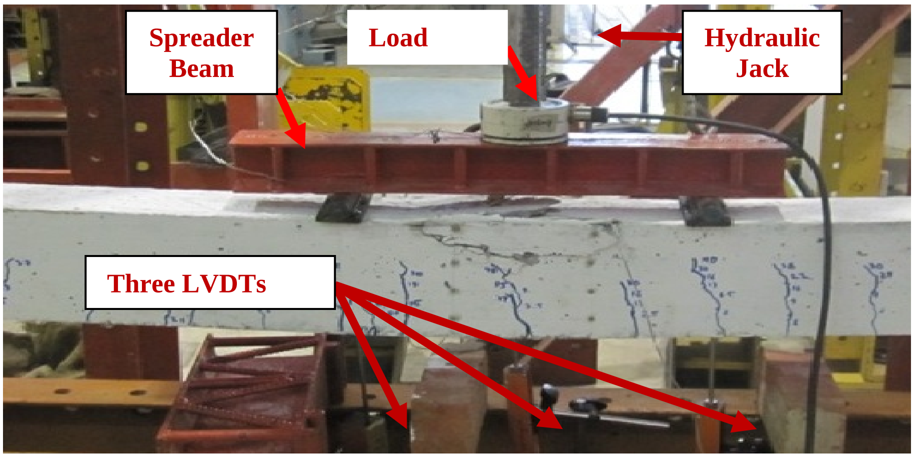


Figure 5: Four-point loading test setup used in this study

4.0 RESULTS AND DISCUSSION

4.1. OPTIMUM PERCENTAGE OF SF IN C30 AND C50 CLASSES OF CONCRETE

The mean values of cube compressive strength of the specimens at the age of 28 days are shown in Table 4. Meanwhile, the results of the four-point loading test on the prisms of C30 and C50 classes of concrete are shown in Tables 5 and 6, respectively. Table 7 shows the results of the Vebe time test.

Table 4: Mean values of cube compressive strength of specimens at the age of 28 days

Specimen label	Mean value of cube compressive strength at the age of 28 days (MPa)	
	C30	C50
RC	32.3	54.8
SFARC-0.5%	37.5	66.3
SFARC-1.0%	38.2	68.5
SFARC-1.5%	35.4	63.0
SFARC-2.0%	32.5	55.1

Table 5: Mean values of flexural strength of prisms of C30 class of concrete at the age of 28 days

Concrete class		Flexural strength (MPa)	Mid-span deflection at ultimate load (mm)
C30	RC	18.0	0.73
	SFARC-0.5%	18.3	0.68
	SFARC-1.0%	19.9	1.12
	SFARC-1.5%	16.9	2.23
	SFARC-2.0%	16.7	2.78

Table 6: Mean values of flexural strength of prisms of C50 class of concrete at the age of 28 days

Concrete class		Flexural strength (MPa)	Mid-span deflection at ultimate load (mm)
C50	RC	18.5	0.81
	SFARC 0.5%	19.0	0.75
	SFARC 1.0%	22.0	1.30
	SFARC 1.5%	17.9	2.55
	SFARC 2.0%	17.5	2.95

As it is obvious in Tables 4, 5 and 6, in both C30 and C50 classes of concrete, specimens containing 1% by volume of the SFs have the highest flexural and compressive strength as compared to other specimens with different percentage of the SFs. In addition, as shown in Table 7, the addition of 1% of the SFs did not have a considerable effect on concrete workability compared to the other SF dosages. The increase in flexural strength can be due to crack-arrest and crack-control mechanism of concrete with the addition of SFs. Furthermore, as shown in Tables 4, 5 and 6 the addition of more than 1% by volume of SFs has led to a decrease in both cube compressive and flexural strength of concrete. This can be due to an appreciable drop in workability of concrete mix with the addition of more than 1% by volume of SFs causing physical difficulties during compaction and casting process of specimens. Therefore, it can be concluded that for this specific type of fibers used in this study the optimum addition of SFs in concrete mix is 1% by volume with respect to both cube compressive and flexural strength.

Table 7: Vebe time test of fresh concrete

Concrete Class	Measured Vebe time of fresh concrete (S)				
	0%	0.5%	1.0%	1.5%	2.0%
C30	1.5	1.75	3.4	7.5	9.8
C50	2.0	2.4	5.0	11.1	14.0

4.2. FLEXURAL BEHAVIOUR OF RC AND SFARC BEAMS

4.2.1. FLEXURAL FIRST CRACKING STRENGTH AND MODULUS OF RUPTURE OF RC AND SFARC BEAMS

The results of flexural test using the four-point loading setup on RC and SFARC beams with 1% of SF by volume are shown in Table 8. As shown in this table, the addition of 1% by volume of SFs (the optimum percentage of SFs used in this study as determined in previous step) led to an increase of 13% and 25% in flexural first cracking load and an increase of 7% and 15%

in ultimate experimental load of SFARC beams of C30 and C50 classes of concrete, respectively. Therefore, it can be concluded that the addition of 1% of SFs in RC beams leads to a higher increase in both flexural first cracking load and ultimate experimental load of beams with higher concrete grade (50 MPa) compared to lower grade of concrete (30 MPa). This can be due to the lower water cement ratio of higher concrete grade (50 MPa) causing less voids in concrete mix and an increase in the fiber-matrix bond strength.

Table 8: Flexural first cracking strength and modulus of rupture of RC and SFARC beams

Beam type	Flexural 1st cracking load (kN)		Ultimate experimental load (kN)	
	C30	C50	C30	C50
RC	7.5	8.0	41.0	42.0
SFARC-1.0%	8.5	10.0	44.0	48.4

4.2.2. LOAD VERSUS DEFLECTION OF RC AND SFARC BEAMS

Figure 5 shows the load versus mid-span displacement of the RC and SFARC beams. The area underneath the graph represents the fracture energy and ductility of concrete beam. As shown in Figure 5, the area underneath load versus deflection graphs of the SFARC beams is bigger than their counterpart RC beams. Thus, it can be concluded that the SFARC beams have more ductility compared to the conventional RC beams. The mid-span displacements at ultimate flexural load of the beams are shown in Table 9. As shown in this table, although the addition of 1% by volume of SFs led to an increase in the ultimate flexural load; however, SFARC beams have lesser deflection compared to their counterpart RC beams. It can be concluded that the stiffness of the SFARC beams is enhanced in comparison with the RC beams.

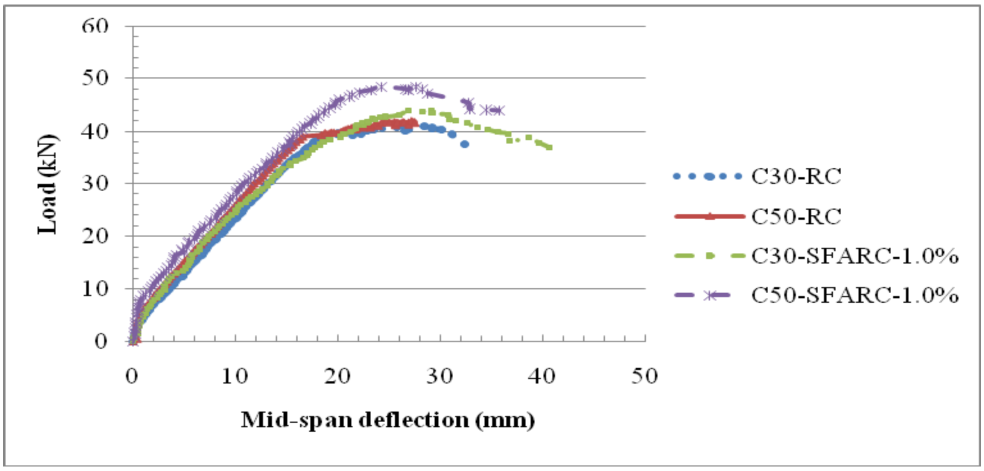


Figure 5: Load Vs. mid-span deflection graph of RC and SFARC beams

Table 9: Mid-span deflection at ultimate flexural load

Beam type	Ultimate flexural load (kN)		Mid-span displacement at ultimate load (mm)	
	C30	C50	C30	C50
RC	41	42	28.46	25.58
SFARC-1.0%	44	48.4	26.9	24.2

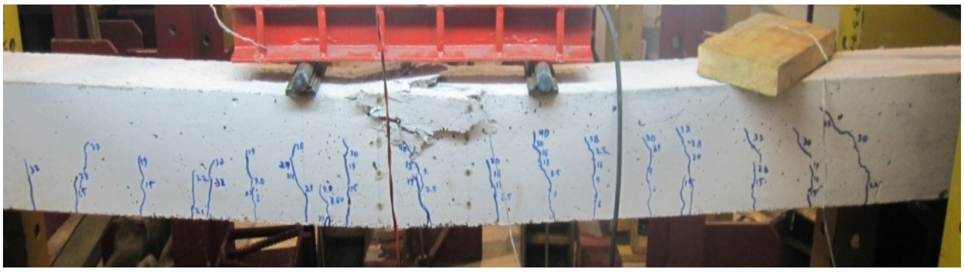
4.2.3. FAILURE MODE OF RC AND SFARC BEAMS

The failure mode of the RC and SFARC beams are shown in Figures 6. As it can be seen in these figures, both the RC and the SFARC-1.0% beams have failed in flexural-tension mode as predicted during the design stage. After failure, the number of cracks and the average crack width of each beam are registered in Table 10.

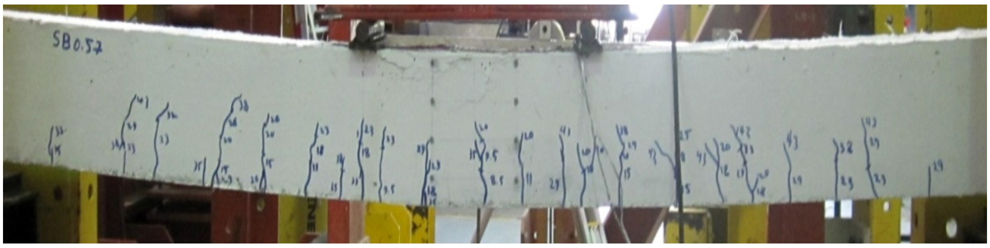
Table 10: Number of cracks and average crack width in RC and SFARC-1.0% beams

Beam type	Number of cracks at failure		Average crack width (mm)	
	C30	C50	C30	C50
RC	19	20	8.2	8.9
SFARC-1.0%	22	25	7.8	6.9

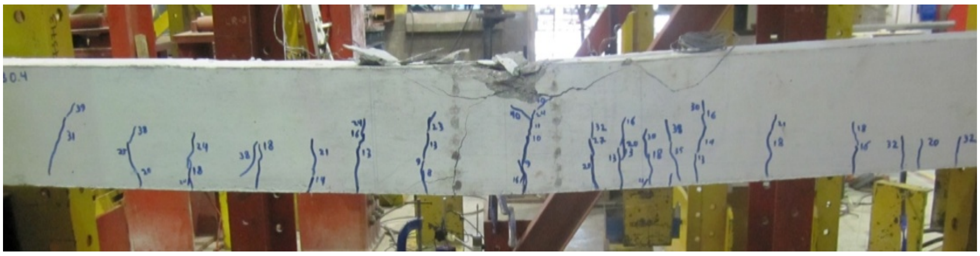
According to Table 10, the addition of 1.0% by volume of SF has led to an increase of 16% and 25% in number of cracks and a decrease in the average crack width of the SFARC beams of C30 and C50 classes of concrete, respectively. Therefore, it can be concluded that the addition of 1.0% by volume of steel fibers in RC beams increases the number of cracks and decreases the average crack width due to the higher ductility behaviour of SFARC beams. Furthermore, the addition of SF has more effect in SFARC beams with higher compressive strength (C50) compared against the lower concrete grade (C30).



(a)



(b)



(c)

(d)

Figure 6: Failure mode and crack pattern of the RC and the SFARC beams; (a)-C30-RC beam, (b)- C50-RC beam, (c)-C30-SFARC-1.0% beam, (d)-C50-SFARC-1.0% beam

5.0 CONCLUSIONS

According to the results of the cube compressive strength test, it is observed that the cube compressive strength of specimens made from C30 and C50 classes of concrete with addition of 1.0% by volume of the SF has increased appreciably compared to other specimens with different percentage of steel fibers. Based on the results of flexural strength test, it is concluded that both the first cracking strength and flexural toughness of prisms made from C30 and C50 classes of concrete with addition of 1.0% by volume of the SFs has increased considerably as compared to those prisms with different percentage of the SFs. Therefore, it can be concluded that in SFARC beams made from concrete grade of 30 MPa and 50 MPa, the optimum percentage of the hooked-end SFs with the dimensions of 0.75 mm in diameter and 50 mm in length is 1.0% by volume with respect to cube compressive strength and flexural toughness and first cracking strength tests. Future study is recommended to investigate the effects of addition of different type of SFs into a high workable steel fiber reinforced concrete.

In accordance with the results of the four-point loading test on the SFARC beams made from C30 and C50 concrete classes with 1.0% by volume of steel fibers, the following conclusions can be drawn:

(i) Addition of 1.0% by volume of SFs in the RC beams increases both the flexural first-cracking strength and flexural toughness of the SFARC beams and leads to an appreciable increase in their ductility and stiffness compared to those conventional RC beams without addition of SFs.

(ii) Addition of 1.0% by volume of SFs has more effects on the RC beams made from the concrete with higher compressive strength (C50) compared to the concrete with lower compressive strength (C30) due to the better bonding between the fibers and the concrete paste.

(iii) 1.0% by volume of the SFs could be applied in the RC beams to get better flexural behaviour.

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