Behavior of Sika Fiber (Force-60) Reinforced Concrete for Construction

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Abstract: This paper describes an experimental study that evaluates the effectiveness of sika fiber force-60 reinforced concrete in terms of its flexural strength and ductility. For this purpose fourteen concrete beams were tested under third point loading. The tested specimens were divided into three groups. The first group contained two plain concrete beams (control specimens), the second group comprised of six wire meshed reinforced concrete beams (wire mesh placed at neutral axis, above the neutral axis and below the neutral axis of beams in each two samples).The third group consists of six fiber reinforced concrete beams (set of each two beams with varying fiber ratios).The result of control specimens were compared with fiber reinforced and wire meshed reinforced specimens. These results expressed that the fiber reinforced concrete specimens were more effective for enhancing the flexural strength and ductility.

Key words: SFRC, wire mesh reinforcement, plain concrete specimens.

1. Introduction

The concrete beam is the most important structural member in the building including slabs and columns. Different types of concrete beams used in the construction of concrete structures. The fiber reinforcement of concrete prism beams was one of the most relevant technique to enhance the capacity of concrete in multidimensional ways. There are many reasons to reinforce the concrete beams such as to enhance flexural strength and ductility. Although different reinforced material for concrete have been used in the past such as natural fiber, steel fiber ,wire mesh reinforcement and fiber reinforcement of many kinds. Now a days, the use of fiber reinforcement has been considered the best internal strengthening material due to their excellent performance in the field of concrete structures especially in beams. The use of SFRC composites as a material with in the prism concrete beams enhanced the flexural strength and ductility. A large number of research studies have been reported in the literature to investigate the different aspects on the fiber reinforced concrete beams and small scale plain concrete specimens [1]-[11]. Most studies emphasized by enhancing the flexure load carrying capacity of reinforced concrete beams. However according to the author's knowledge no research had been conducted to study the effect of sika fiber force-60 reinforced concrete on the medium scale on reinforced concrete prism beams. In the present study, the performance of sika fiber force-60 reinforced concrete beams, plain concrete prism beams and wire meshed reinforced concrete specimens were investigated in terms of its flexural strength and ductility. The main objective of the study is to provide an insight into the effectiveness of SFRC reinforcement over the plain and other wire meshed reinforced concrete prism specimens.

2. Experimental Program

In order to study the effectiveness of sika fiber force-60 reinforced concrete specimens over plain and wire meshed reinforce concrete specimens. A total of fourteen beams were casted along with their strength controlling concrete cylinders in concrete laboratory, at University of Engineering and Technology, Taxila, Pakistan. The beams were categories into the following three groups.

1) Beams without reinforcement (plain cement concrete, control specimen).

2) Beams with wire meshed reinforcement, placed at three different location (at neutral axis, above the neutral axis and below the neutral axis)

3) Beams with reinforcement of fiber force-60 at varying fiber ratios on each set of beams.

Each specimen in all three groups have size, 500mm in length, 100mm in width and thickness. The set of beams in group 1 consisted of control specimens made up of plain concrete. Group 2 consists of six beams having wire meshed reinforcement in each set of two beams placed at three different locations i.e. at neutral axis, above and below the neutral axis. Group 3 comprised of six fiber reinforced concrete beams with varying fiber mixing ratio in each set of beam i.e. 3kg/m^3, 6kg/m^3 and 9kg/m^3 respectively.

The detail of fiber and admixture used in concrete were provided by the manufacturer are shown in Table 1& Table 2 respectively.

Table 1. Properties of Admixture (Sika Viscocrete 3110)

Solid content	51.2%
Chloride content	0.02%
Water reduction rate	30%
Density	1.11 g/ml

Table 2. Properties of Sika Fiber Force-60

Tensile strength	430 MPa
Tensile modulus	6GPa
Length & diameter	60mm&0.84mm
Melting point	170 ℃
Recommended dosage	3-10 kg/m^3
density	0.91 kg/l

Table 3. Concrete Properties

Compressive strength	20MPa
Slump	100mm
Concrete mix ratio	1:2.44:3.64
Aggregate size	2-20mm
Water cement ratio(w/c)	0.56
Admixture ratio	0.6%
Lab.temperature	27 ℃

All the concrete beams were casted in a horizontal position as shown in Fig. 2, the ingredients used in the concrete mix design were sand, water, coarse aggregates (aggregate with maximum size 20mm) and ordinary Portland cement. The steel wire mesh and sika fiber also introduced in concrete mix. The mix ratio 1:2.44:3.64 with water cement ratio (w/c) 0.56 were used in the preparation of concrete mix design. In order to remove air from concrete during casting of prism beams, compaction was carried out using temping rod as shown in Fig. 2, the six cylinders of 150mm×300mm size were casted from the control specimen concrete mix in order to check the compressive strength of concrete.

The uniform concrete mixing was carried using concrete mixer as shown in Fig. 3 then concrete was poured into the moulds. The average of three strength controlling cylinders at the test date shown in Fig. 4. After 24 hours of casting, the test specimens were removed from the moulds and placed in curing tank under laboratory conditions until the time of testing. Three cylinders were tested at 7-days as seen in Fig. 7, the rest of the three cylinders tested at the age of 28-days.however all the beams specimens were tested under third point loading at the age of 28-days.

2.1. Reinforcement of Sika Fiber Force-60 and Wire Mesh in Beam Specimens

The surface of prism beam moulds cleaned properly from dust, laitance, loose particles and other bond inhibiting materials with steel wire brush, then oiled to smoothen the surface. The wire meshes placed at desired locations before concrete poured into it by ensuring proper compaction with temping rod. The SFRC prepared at different ratios, dry mixing of fiber carried out for each proportion then admixture added in wet concrete. All the three proportion of SFRC were prepared and poured into the moulds. Allowed to set for 24hours then removed from moulds and placed in curing tank till final testing date.

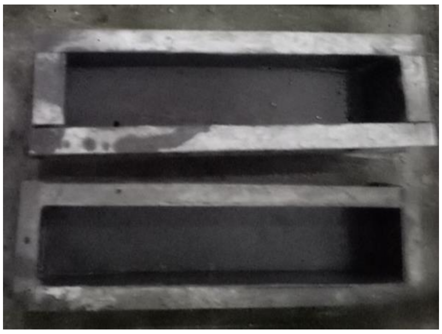

Fig. 1. Steel moulds for beams.

Fig. 2. Application of temping rod.

Fig. 3. Concrete mixer.

Fig. 4. Slump test of fresh concrete.

Fig. 5. Placement of steel wire mesh in moulds.

Fig. 6. Casting of fiber reinforced concrete.

Fig. 7. Compressive strength test of cylinders.

Fig. 8. Arranged concrete specimens after testing.

2.2. Instrumentation and Testing Procedure

The compression testing machine set up was presented in Fig. 9, the compressive strength of cylinders were tested as per ASTM C-39 and third point loading test was adopted to check the flexural strength of beam specimens as per ASTM C78-02 as shown in Fig. 10.

Fig. 9. Arrangement of cylinder in compression testing machine.

Fig. 10. Arrangement of beams specimen for testing.

3. Test Results and Discussions

3.1. Test Observation and Failure Mode

All the beams were failed in a typical flexural failure mode, almost within the middle span.it was observed that control specimens failure occurs at 22.5cm&16.5cm from adjacent support respectively as shown in Fig. 11 and cracks developed throughout the width. The brittle failure occurs at the load of 13KN.

It was observed that beams with wire mesh reinforcement at neutral axis failed exactly at mid span (22cm) from supports. The brittle failure occurs at 12KN load by originating crack throughout the width as shown in Fig. 12.

The beams with wire mesh reinforcement above the neutral axis, the specimen failed at a distance of 21.5cm&16cm from adjacent support, brittle failure occurs at a load of 12KN with cracks originating through the width section as shown in Fig. 13.

When wire mesh placed below neutral axis with in the tension zone of beam pair then the behavior of specimen changes, cracks developed at distance of 13.5cm&20.5cm from adjacent supports with abrupt failure at 13KN load as shown in Fig. 14.

It was observed that beams with fiber reinforcement (3kg/m^3), failure mode changes from brittle to ductile, failure load was 13KN and cracks propagated at distance of 22.5cm&16cm from adjacent support as shown in Fig. 15.

Pair of Beams with fiber ratio (6kg/m^3) enhanced the flexural load carrying capacity to 14KN&15KN respectively as well as show ductile failure mode with cracks propagated at a distance of 22cm&16.5cm from adjacent support. Micro to macro cracks developed as shown in Fig. 16.

Beams specimens having fiber ratio upto 9kg/m3 were tested and gives excellent results in terms of flexural strength and ductility. The load carrying capacity enhanced upto 14KN&15KN respectively at failure load, furthermore the micro cracks originating at a distance of 17cm&20cm from adjacent support as shown in Fig. 17. Moreover the micro cracks appeared with increasing load, cracks expended slightly at failure just upto the half depth of beam. The cracks starts originating from bottom and moves towards upward to the half depth of beams. These were due to the fact that fiber reinforcement provided resistance against flexure load and brings ductility in concrete.

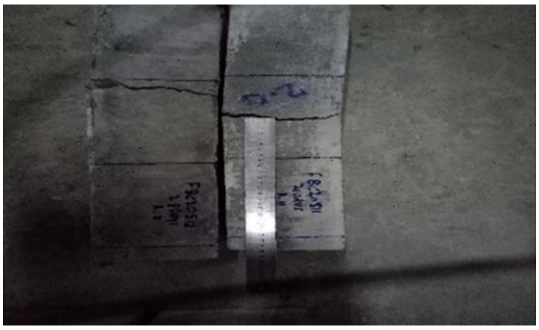

Fig. 11. Failure mode of control specimens.

Fig. 12. Failure mode of wire mesh specimen (at neutral axis).

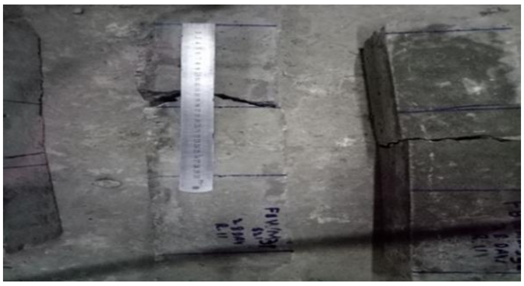

Fig. 13. Failure mode of wire mesh specimens (above neutral axis).

Fig. 14. Failure mode of wire mesh specimens (below neutral axis).

Fig. 15. Failure mode of fiber reinforced specimens (3kg/m^3).

Fig. 16. Failure mode of fiber reinforced specimens (6kg/m^3).

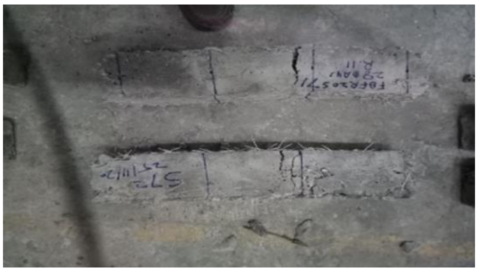

Fig. 17. Failure mode of fiber reinforced specimens (9kg/m^3).

3.2. Comparison of Wire Mesh Reinforced Specimen with Control Specimen Beams

Fig. 18 shows effectiveness of a single layer wire mesh reinforcement with in the beam and comparison with control specimens. The numbers 1-4 on the x-axis indicate the following aspects.

1) Plain concrete beams (control specimens) test-1.
2) Wire meshed reinforced concrete beams with wire mesh placed at neutral axis (test-2).
3) Wire meshed reinforced concrete beams with wire mesh placed below the neutral axis (test-3).
4) Wire meshed reinforced concrete beams with wire mesh above the neutral axis (test-4).

It represents the results of control specimens(test-1) and WMRC beams (test 2-4).it is evident from results that WMRC beams below neutral axis in test-3 gives same results as of control specimens in test-1.Contrary to this, placement of wire meshes in other both location as judged in test 2&4 decreases the flexural strength as compared to control specimens in test-1.It is therefore concluded that wire mesh reinforcement in tension zone of beams gives better results as compared to other placement positions.

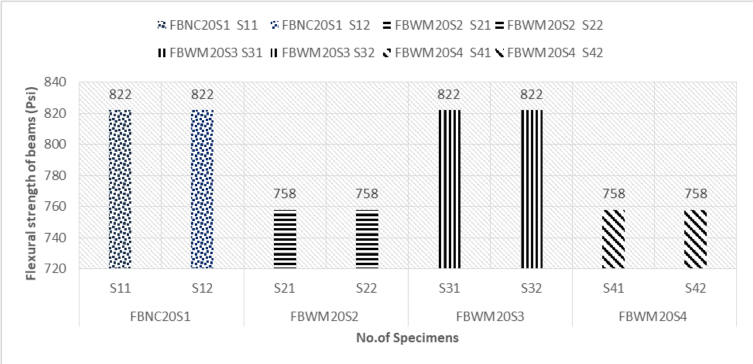

Fig. 18. Comparison of control specimens with WMRC beams.

3.3. Comparison of Fiber Reinforced Beams and Control Specimens(Pcc)

Fig. 19 shows the behaviour of fiber reinforced concrete specimens and control beams specimens. On x-axis from 1-7 following results were compared.

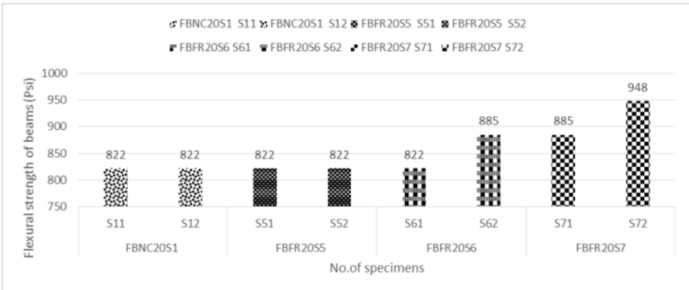

Fig. 19. Comparison of control specimens with SFRC beams.

1) Plain concrete (control specimens) beams (test 1).
2) Fiber reinforced beams with 3kg/m^3 (test 5).
3) Fiber reinforced beams with 6kg/m^3 (test 6)
4) Fiber reinforced beams with 9kg/m^3 (test-7)

It is evident that fiber reinforcement enhanced the flexural strength of beams in test 6&7 with increasing trend as per addition of fibers.it is therefore ductile failure occurred with multi micro cracks, macro cracks opening appeared on beams surface as shown in Fig. 17, at minimum fiber ratio in test 5, the strength is remain same as control specimens but beams failure mode were changed from brittle to ductile as compared in Fig. 15.

3.4. Comparison of Wire Meshed and Fiber Reinforced Beams.

It is evident from Fig. 20 that wire meshed placed at neutral axis in beams test 2 shows less flexural strength as compared to the SFRC specimens with varying fiber ratios 3kg/m3-9kg/m^3 as in test 5-7.the brittle failure occurred in test 2 while in test 5-7 ductile failure observed, it is therefore examined that addition of fibers was better as compared to wire mesh reinforcement both in terms of flexural strength and ductility.

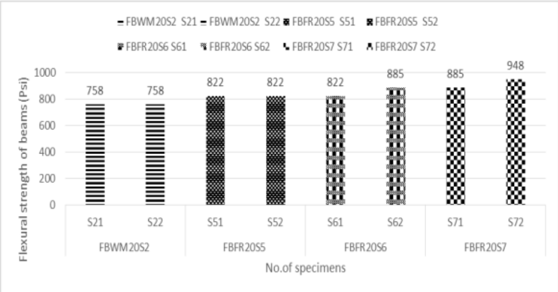

Fig. 20. Comparison of fiber reinforced concrete specimens with WMRC beams.

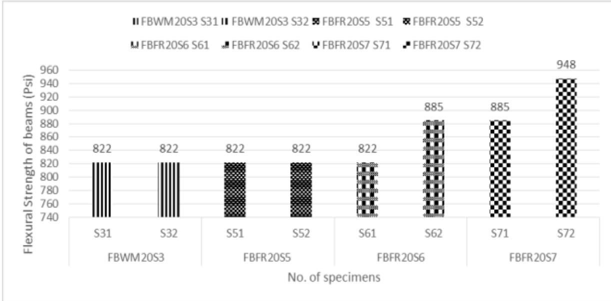

Fig. 21. Comparison of SFRC specimens with WMRC beams (below neutral axis).

It is evident from Fig. 21 that wire meshed placed at neutral axis in beams, test 3 shows same flexural strength as compared to SFRC beams ta minimum fiber ratio in test 5 but the matter of concern is that failure mode of both tested specimen were different. Test 3 shows brittle failure as shown in Fig. 14 while test 5 specimens shows ductile failure as shown in Fig. 15, the remaining test 6&7 specimens shows increased flexural strength as well as more ductility as shown in Fig. 16 & Fig. 17 respectively.

It was examined from Fig. 22 that wire mesh placed above neutral axis in beams, test 4 shows less flexural strength as compared to SFRC specimens. Also brittle failure occurred in test 4 while ductile failure taken place in test 5-7 specimens.it is therefore concluded that SFRC specimens was better in terms of flexural strength and ductility.

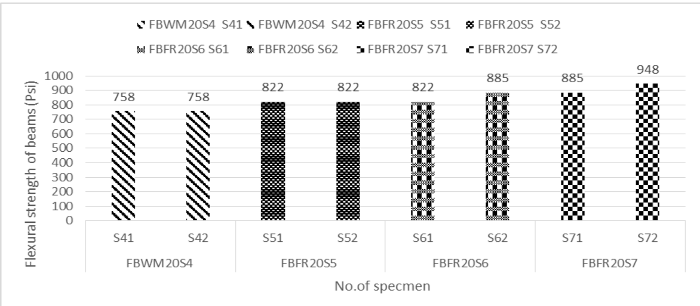

Fig. 22. Comparison of SFRC specimens with WMRC beams (above neutral axis).

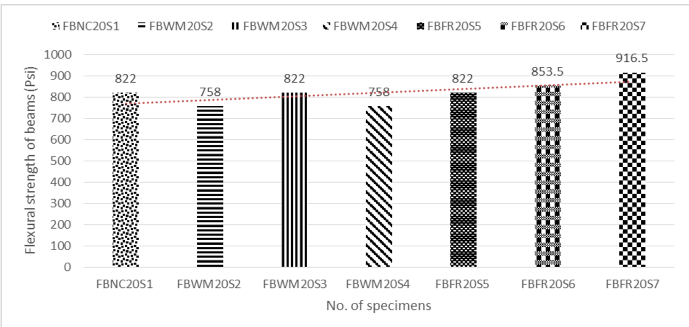

Fig. 23. Comparison of SFRC, WMRC and control specimens.

3.5. Overall Comparison of Results

It is evident from Fig. 23 that the control specimens in test 1, wire meshed specimens (placed below neutral axis) test 3 and fiber reinforced beams with fiber ratio 3kg/m3 as in test 5 represented the same flexural strength. Furthermore addition of fibers in test 5 specimens changes the failure behavior of beams which found to be ductile. The wire mesh reinforcement at neutral axis as in test 2 and above neutral axis as in test 4 represents 7.78% less flexural strength as compared to control specimens. The only gain in flexural strength found in test 6 upto 3.83% and 11.49% in test 7 specimens having increased fiber ratios as compared to control specimens.

Table 4.Compressive Strength of Concrete Cylinders

Sr.no	Designation		Mix	% of fiber (by volume of concrete)	No.of specimens	Test age	Compressive load (KN)	Compressive strength(Psi)	Average value (Psi)
1	CC20C1	C11	M20	No reinforcement of any kind	1	7 days	280	2226	2377 (79%)
		C12			1		277	2202	
		C13			1		340	2703	
2	CC20C2	C21			1	28 days	394	3132	3280
		C22			1		435	3458	
		C23			1		409	3251	

Table 5. Flexural Strength of Concrete Beams

Sr.no	**Designation**		**Mix**	**% of fiber**	**No.of specimen**	**Test age**	**Load p (KN)**	**A (cm)**	**Mass (gm)**	**Flexural strength $R=PL/bd^2$ (Psi)**	**Average value (Psi)**
1	FBNC20S1	S11	M20	No reinforcement	1	28 day	13	22.5	12676	822.09	822.09
		S12			1		13	16.5	14016	822.09	
2	FBWM20S2	S21	M20	Wire mesh placed at neutral axis	1	28 day	12	22	12992	758.8	758.8
		S22			1		12	22	12933	758.8	
3	FBWM20S3	S31	M20	Wire mesh placed below the neutral axis	1	28 day	13	13.5	13443	822.09	822.09
		S32			1		13	20.5	13065	822.09	
4	FBWM20S4	S41	M20	Wire mesh above the neutral axis	1	28 day	12	21.5	12808	758.8	758.8
		S42			1		12	16	12647	758.8	
5	FBFR20S5	S51	M20	$3kg/m^3$ sika fiber	1	28 day	13	22.5	13855	822.09	822.09
		S52			1		13	16	13315	822.09	
6	FBFR20S6	S61	M20	$6kg/m^3$ sika fiber	1	28 day	13	22	12964	822.09	853.6
		S62			1		14	16.5	12452	885.3	
7	FBFR20S7	S71	M20	$9kg/m^3$ sika fiber	1	28 day	14	20	13172	885.3	916.5
		S72			1		15	17	14066	948.5	

4. Conclusion

The key focus of this experimental study was to provide an insight into the behaviour of plan concrete (control specimens), wire meshed and fiber reinforced concrete specimens with varying fiber ratio to gain flexural strength and ductility.

The following conclusion were drawn from this experimental investigation.

1) The role of sika fiber became immaterial in enhancing the flexural strength and ductility of concrete beams.

2) The effect of SFRC were more evident with rest of the control and wire meshed specimens as failure mode of SFRC was ductile where as others have brittle failure.

3) The flexural strength of SFRC beams have enhanced upto 3.83% when fiber added 6kg/m^3.

4) Flexural strength of SFRC beams increased upto 11.49% when fiber addition approaches to 9kg/m^3.

Based on these experimental investigation, the SFRC was found very effective to enhance flexural strength and ductility of the concrete specimens.it is therefore suggested to use these SFRC for beams as well as for other structural members where flexural loads mainly concentrated.

Appendix-Abbreviations

FBNC: Flexural beams with normal concrete
FBWM: Flexural beams with wire mesh
FBFR: Flexural beams with fiber reinforcement
A: Distance of cracks from adjacent support
WMRC: Wire meshed reinforced concrete
SFRC: Sika fiber reinforced concrete

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Author 1, conducted the research including literature review, casting the specimens, experimentation, wrote the paper and final paper submission; Author 2, 3 and 4 analyzed the data and all authors had approved the final version.

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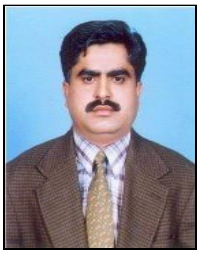

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