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The Influence of Steel and Basalt Fibers on the Shear and Flexural Capacity of Reinforced Concrete Beams

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Abstract: To improve the shear and flexural capacity of flexural members, the steel and basalt fibers were used in model beams tested under flexure. Three series of single span free supported model beams were prepared from SFRC (steel fiber reinforced concrete) with longitudinal steel reinforcement (steel ratio of 1.2 %) and varied spacing of steel stirrups and they were tested till failure. Another three series of BFRC (basalt fiber reinforced concrete) double-span model beams with a span of 2 mm × 1,000 mm and cross section 180 mm × 80 mm were tested. During the tests till to the failure the beam reactions, vertical deflections and horizontal strains in concrete were registered, to clarify the range of redistribution of bending moments and shear forces over the span of the beams. Almost all the tested model beams failed in shear, showing visible influence of steel and basalt fibers on the shear capacity of the tested beams. The tests results confirmed that steel and basalt fibers in reinforced concrete beams can partially replace (in certain cases) the traditional steel stirrups calculated for shear.

Key words: Steel and basalt fiber reinforced concrete, stirrups, shear capacity.

1. Introduction

With the development of concrete technology, there are developed new ways for improving the parameters of concrete structures. One method to change the mechanical properties of the concrete is the addition of fibers: steel, plastic, carbon, basalt, glass and even organic origin. The use of fibers in concrete structures may contribute to improve structural behavior of the members, e.g., crack propagation, shrinkage strains reduction, bond strength and in some cases, fibers may be used as a full or partial replacement of flexural or shear reinforcement. In the last case, the authors have to do with mixed reinforcement for shear. This problem was analyzed in past amongst others by Lim and Oh [1]. They present experimental and theoretical investigation on the shear of steel fiber reinforced concrete beams. The test results indicate that fiber reinforcement can reduce the amount of shear stirrups required and that the combination of fibers and stirrups may meet strength and ductility requirements. Domanski and Czkwianianc [2] investigated a double-span beam with steel fibers and polypropylene fibers reinforcement analyzing the effects of deformations in shear zones. Application of fiber mesh has had a favorable effect on strains in stirrups after appearances of shear cracks. Recent experimental studies on shear effects in SFRC (steel fiber reinforced concrete) beams have been done by Dinh et al. [3], he has studied the behavior of beams with steel fibers on the shear capacity of 28 simply supported beams. Studies have shown beneficial effects of hooked steel fibers at 0.75% by volume. Aouda et al. [4] studied the response of steel fiber-reinforced concrete beams with and without stirrups. A series of nine full-scale reinforced concrete and steel fiber-reinforced concrete beams have demonstrated that the addition of fibers leads to improve shear resistance in shear-deficient beams. Salna and Marciukaitis [5] analyse the influence of steel fiber volume and shear span ratio on the strength of fiber reinforced concrete elements in various states of stress. The experiment shows that steel fiber volume has different influence at different shear span

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ratio. The paper presents the results of investigation on shear and flexural behavior of single-span and double-span beams with mixed reinforcement: flexural steel bars and steel or basalt fibers [6].

2. Fibers Used in the Experiment

2.1 Steel Fibers

The use of steel fibers prevents the development of shrinkage cracks and brittle cracking of concrete due to quasi-plastic nature of the SFRC. The addition of steel fibers has the greatest impact which is the tensile flexural strength. Also it has a major impact on the toughness and resistance to abrasion and fatigue loads [7]. The studies in recent years reveal an increased energy damage, reducing shrinkage to 40% and an increase of the modulus of elasticity up to 25% [8]. To modify the concrete mix, there were used steel fibers with a length of 50 mm and a diameter of 1 mm made of round wire, cold drawn, low carbon steel (as shown in Fig. 1). Steel fibers were dispensed to the concrete mix in an amount of 1.5% by volume of concrete.

2.2 Basalt Fibers

In the experimental studies of model beams, there were also used basalt fibers (Fig. 2). They are characterized by high tensile strength 1,680 MPa and modulus of elasticity 90 GPa. The fibers are straight, circular with diameter equal to 16 μ and the length 50 mm. Basalt fibers are resistant to corrosion and acid and also against alkaline environment. They are characterized by excellent resistance to high and low temperatures from -260 ^{o}C to +750 ^{o}C. They are coated with a polymer affecting the optimum adhesion to concrete. An additional advantage of such fibers is high hardness (8.5 by Mosh), what greatly affects the increase in concrete resistance to abrasion. The advantage of basalt fiber as compared to steel fiber is its low weight (three times lighter than steel) [9].

3. Material Properties

About steel and basalt fiber-reinforced concrete, mechanical tests on samples made of SFRC and BFRC (basalt fiber reinforced concrete) have been conducted. It has been designed two types of concrete depending on the addition of steel or basalt fibers.

For preparation of SFRC model beams (with steel fibers) Portland cement CEM I 32.5 R and natural aggregates, having grain size of 0.125-4 mm. To improve the workability of the composite mixture a super plasticizer was used. In the mix water to cement ratio was equal to 0.67 [9]. For preparation of BFRC model beams a natural aggregate fraction of 0-4 mm having the sand point equal to 68% has been used. The amount of cement CEM I 45.5 used was equal to 500 kg/m^3 and water—350 kg/m^3 (the w/c ratio was equal to 0.7). In connection with the use of fibers an admixture of super plasticizer in a 1% by weight of cement has been applied [9].

The compressive strength of SFRC and BFRC were evaluated on cubic samples with dimensions of 100 mm × 100 mm × 100 mm. The flexural tensile strength was evaluated through four-point bending test on 100 mm × 100 mm × 400 mm prisms. Two types of samples were performed with the addition of steel

Fig. 1 Hooked steel fibers used in the model beams.

Fig. 2 Chopped basalt fibers used in the study.

fibers in the amount of 1.5% by volume and basalt fibers in the amount of 20.0 kg/m^3 (by mass). Also the reference samples of concrete without the addition of fibers were tested.

The test results of compressive strength and tensile flexural strength are presented in Table 1. As can be seen, there were no indications of compressive strength increase. While the tensile flexural strength for samples with basalt fibers increased by 62% and with steel fibers increased by 42%. It have been also noticed an increase of cracking resistance of the SFRC and BFRC prisms. Also a quasi-plastic behavior of these prisms before failure has been observed [9, 10].

4. Assumptions for the Experimental Research

4.1 The Aim of the Study

An experimental program was conducted to analyze the influence of steel and basalt fibers on the behavior of the shear zone in single—and double-span model beams with flexural steel longitudinal reinforcement. The main assumption was that the steel or basalt fibers in the concrete mix will allow the total or partial replacement of the traditional shear reinforcement (steel stirrups). The use of fibers in the shear zones may be a way to reduce the effects caused by the shear force, as well as reducing the width of the inclined crack. The study was carried out on the model beams with varied steel stirrup spacing at the beam length compared to the reference beams without fibers.

4.2 Assumption for Testing Beams with Steel Fibers

Single-span reinforced concrete beams with a cross section 80 mm × 120 mm and the span 1,100 mm were loaded till failure. The reinforcing flexural steel bars are made of steel with a yield strength f_y of 500 MPa, and the steel of stirrups have the yield strength f_y of 220 MPa. The details of SFRC model beams are presented in Fig. 3. Depending on steel fiber content and arrangement of steel stirrups 3 series of model SFRC beams have been performed containing three samples in each series [10]. In any series, the spacing of steel stirrups was differenced at the left and right half span of each model beam (as shown in Fig. 3).

4.3 Assumption for Testing Beams with Basalt Fibers

The tests were carried out on the three series of pilot-scale two-span continuous BFRC beams reinforced for flexure with steel bars. The beams had the effective spans of 2 mm × 950 mm and the cross-section of 180 mm × 80 mm. The top and bottom reinforcing flexural steel bars of 2Φ 10 (A_s = 1.57 cm^2) were assumed with a reinforcement ratio of 1.2%. The longitudinal flexural reinforcement had an average yield strength f_y of 500 MPa. The 6 mm steel stirrups used in the study were made from low carbon steel with the same yield strength [9].

Due to the variability of shear force and an attempt to reduce the required steel stirrups cross-section by using basalt fibers in the tested beams were assumed different spacing of the stirrups. The reinforcement details are shown in Fig. 4.

4.4 Experimental Procedure

All the beams were tested on a standard testing machine with a capacity of 200 kN. The scope of tests

Table 1 The mechanical properties of SFRC and BFRC [9, 10].

Volume of fibers	Compressive strength (Mpa)	Increase of strength (%)	Tensile flexural strength (Mpa)	Increase of strength (%)
(%)			SFRC	
0	29.62	-	4.560	-
1.5	30.58	3.24	6.480	42
(kg/m^3)			BFRC	
0	29.7	-	3.70	-
20	29.8	0.3	5.97	62

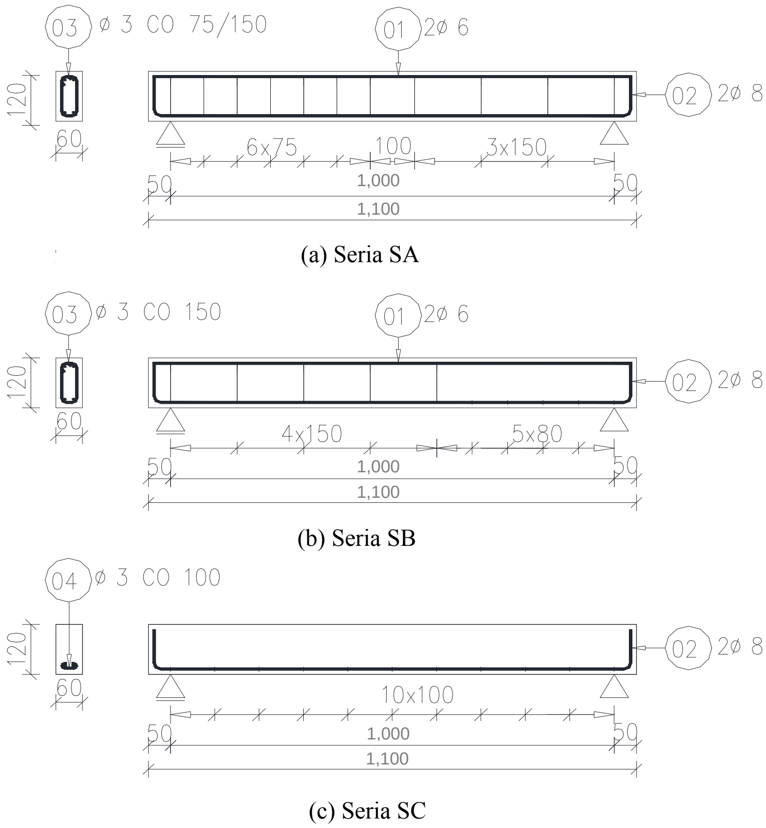

Fig. 3 Details of three series of tested SFRC beams: SA, SB and SC [10].

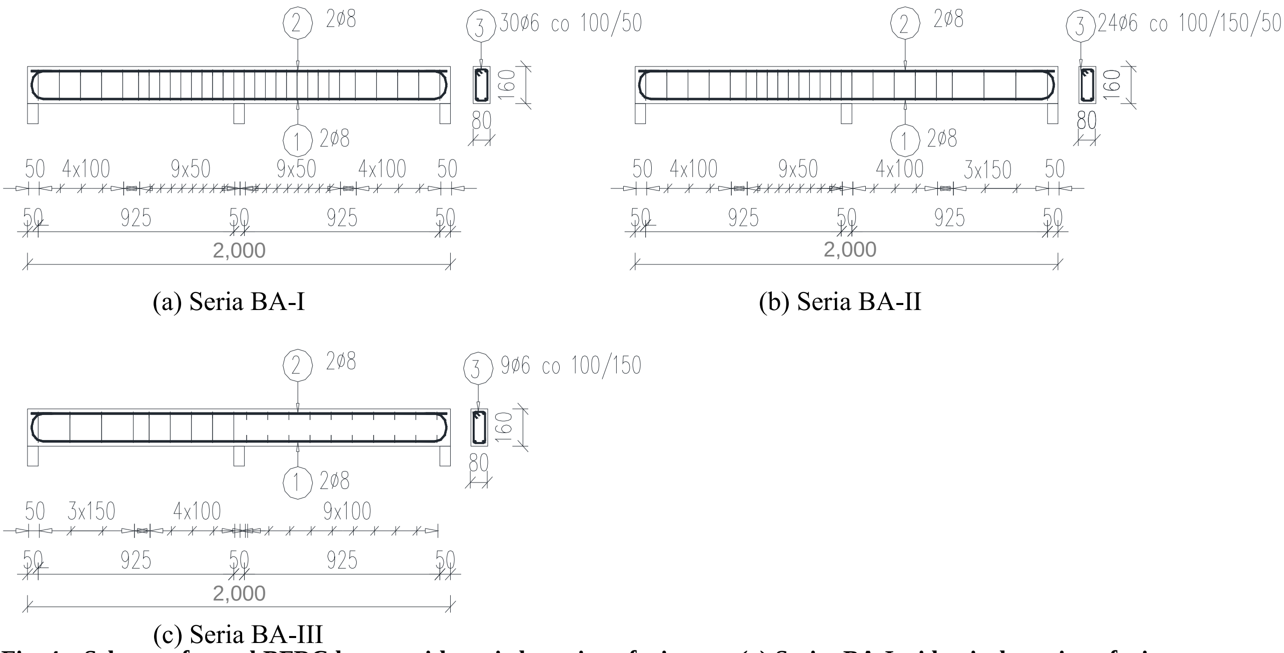

Fig. 4 Scheme of tested BFRC beams with varied spacing of stirrups: (a) Series BA-I—identical spacing of stirrups on two spans; (b) Series BA-II—right span with twice increased spacing of stirrups compared to Series A-I; (c) Series BA-III—right span without stirrups [9].

included the measurement of beam deflection, crack width control, control of the longitudinal concrete strains at several levels of cross-sections and determination the critical beam load under failure.

5. Experimental Results

5.1 Effect of Fiber on Model of Failures

Eight of the nine tested SFRC model beams were failed in shear. Only one beam has failed due to flexure. Fig. 5 shows the destructive diagonal cracks in the tested beams. The failures caused by the shear force occurring on this side of the beam, where the stirrups was used at twice increased spacing of stirrups or they were not used at all. The qualitative results of these tests are presented in Table 2.

BFRC two span model beams of Series BA-I and BA-II failed in flexure in the right span with a reduced spacing of stirrups. In Fig. 6, the BFRC beams of Series A-III failed in shear in the right span without stirrups. In this figure, it can be seen only one diagonal crack that caused the failure.

5.2 The Effect of Fibers on Shear Capacity of the Beams

The test results obtained for SFRC model beams are presented in Table 2. The reference beam of Series SB-0 (without fibers) was failed after reaching the load F = 24 kN. For a Series of SA-1 and SA-2 beams (with steel fibers) critical loads were equal to 34 kN. For the beams with twice increasing spacing of the stirrups the beam of Series SB-0 was destroyed reaching the critical load F = 22 kN whereas the beams with addition of steel fibers (Series SB-1, SB-2) reached the critical loads F = 32 kN. Critical load for a reference beam of SC-0 prepared without reinforcement stirrups was equal 28 kN whereas for the beams SC-1 F = 28 kN and for the beams SC-2 F = 30 kN.

The tested model beams with steel fibers for all the test series showed an increase shear capacity by about 45%.

Fig. 5 The failure modes of selected SFRC beams after testing [10].

Fig. 6 Damaged beam series BA-III with one diagonal crack [9].

Table 2 Critical forces for each series of model SFRC beams [10].

Series of beams	Maximum critical experimental load (kN)	Experimental critical shear capacity (kN)	Increase of theoretical shear capacity (%)
SA-0	24	12	-
SA-1	34*fail in bending	17	42.0
SA-2	34	17	42.0
SB-0	22	11	-
SB-1	32	16	45.0
SB-2	32	16	45.0
SC-0	20	10	-
SC-1	28	28	40.0
SC-2	30	30	50.0

Table 3 Critical forces and moments for each series of model BFRC beams [9].

Series of beams	Maximum critical experimental load	Theoretical critical shear capacity	Experimental critical shear capacity	Increase of theoretical shear capacity	Theoretical flexural capacity	Experimental flexural capacity	Increase of flexural capacity
	(kN)	(kN)	(kN)	(%)	(kNm)	(kNm)	(%)
BA-II	65.0 right span	-	-	-	9.65	19.57	102.80
BA-III	35.0 right span	15.08 (Eq. 1)	20.49	36.0	-	-	-

The selected results obtained for tested two-span BFRC model beams are presented in the Table 3. The beam of Series BA-III failed by shear in the right span of the beam (without steel stirrups) for the destructive load equal to $F = 35$ kN.

Table 3 presents the results of experimental and theoretical shear and flexural capacities of tested model beams of Series BA-II and BA-III. Critical experimental flexural capacity for the beams BA-II was about 100% higher compared to theoretical values (calculated on the basis of RC section). However the beams from series of BA-III, failed in shear revealed the increase of shear capacity about 36 % compared to theoretical value calculated for the RC beam sections without steel stirrups on the basis of Model Code 2010 provisions [11].

6. Conclusions

The results of experimental studies showed that the effect of steel and basalt fibers on the compressive concrete strength is not significant, whereas the beneficial effect was observed for concrete tensile strength. Steel fibers added in a 1.5% volume ratio showed a 40% increase in tensile flexural strength. The addition of 20 kg/m^3 of basalt fibers resulted in about 60% increase of tensile flexural strength compared to plain concrete tensile strength (without fibers).

The pilot studies conducted on SFRC and BFRC model beams with different spacing of steel stirrups showed an positive effect of basalt fibers on flexural and shear capacity of reinforced concrete members.

In all the tests conducted for SFRC model beams, it was observed an improvement of shear and flexural capacity compared to reference reinforced concrete beams without fibers. An increase of critical shear forces estimated to be about 42%-50% compared to the reference beams without fibers.

The test results of model BFRC beams showed a distinct increase in carrying flexural and shear capacity, compared to the theoretical capacities calculated on the basis of RC sections (with no use of basalt fibers). The beams of Series A-III (without stirrups in the right span) were failed in shear under the critical load about 36% larger that theoretical shear capacity calculated on the basis of RC member without shear reinforcement.

The results of these pilot tests clearly showed the improvement of failure behavior of SFRC and BFRC beams under load without brittle destruction due to quasi-plastic characteristic of concrete.

The further experimental and numerical tests are planned to explain the use of BFRC beams in continuous two-span beams of natural scale.

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