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EFFECT OF FIBER TYPES ON SHEAR STRENGTH OF FIBRE REINFORCED CONCRETE UNDER DIRECT SHEAR

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Abstract

The paper reports the results of an investigation on the strength and ductility of steel fibre reinforced concrete (SFRC) under direct shear. Steel fibre reinforced concrete "push off" specimens according to ACI SP-105 [1] were tested. Two types of steel fibres: short fibres OL Dramix 6.0/0.16 and high corrosion-resistant long fibres Fibraflex were used. The influence of fibre volume on shear resistance of FRC for individual types of fibres as well as their combinations were investigated. Test results obtained indicate higher effectiveness of fibres OL Dramix 6.0/0.16 than Fibraflex.

Keywords: steel fiber reinforced concrete; "push-off" specimen; direct shear; shear resistance.

1 Introduction

For more than 40 years, SFRC has been the object of numerous investigations. Most of these investigations focused on behaviour of SFRC in tension because steel fibers are well known to improve the tensile strength of concrete matrix. The use of fibers to improve the shear behaviour of concrete is also promising. However, there are a few results of investigation of shear behaviour until now, e.g. [2-5].

Using combination of short and long steel fibers can partly limit process of initiation and propagation of cracks and prevent concrete structures before sudden collapse. It is assumed that the short fibers, which are uniformly dispersed in the whole of concrete volume, bridge microcracks, and long steel fibers are effective in first stages of macrocraks initiation.

The paper provides the results of an experiment of 36 "push-off" specimens, in which, the effect of fibre volume on shear resistance of FRC for individual types of fibres as well as their combinations was investigated.

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2 Experimental program

2.1 Specimens and materials

The specimens had dimensions of 400 x 300 x 150 mm, with a shear plane area of 15000 mm^2 (**Fig. 1**). These dimensions were determined according to [1]. The investigated parameters in the experiment were: a) type of fiber, b) combination of fiber types and c) fiber amount. By combination these parameters, seven different types of specimens were obtained (**Tab. 1**).

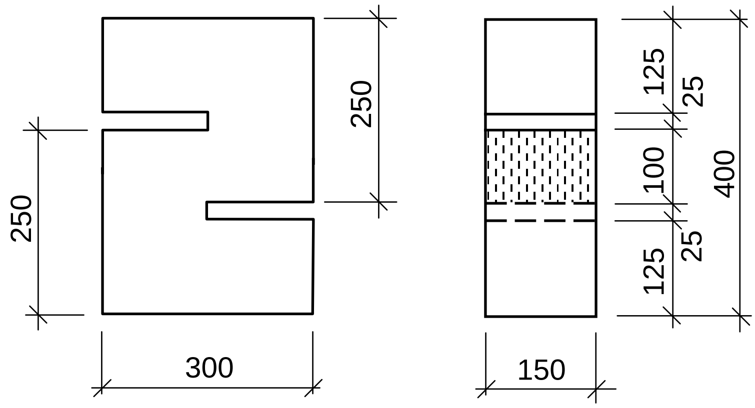


Fig. 1 Details and dimensions of "push-off" specimens

Tab. 1 Specimen types

Specimen groups	Fiber type	Fiber amount (kg/m^3)	Number of tests
Sa0		0	12
Sa1	OL	90	4
Sa2		120	4
Sa3	FF	90	4
Sa4	FF+OL	45+45	4
Sa5		30+60	4
Sa6		60+30	4

Two types of steel fibres: short fibres OL Dramix 6.0/0.16 (marked as OL) and high corrosion-resistant long fibres Fibraflex FF30L6 (marked as FF) were used. The parameters of the investigated fibers are shown in **Tab. 2**.

Tab. 2 Parameters of the investigated fibers

Fiber	Length (mm)	Dimensions (mm)	Cross-section shape	Tensile strength (MPa)	Elastic modulus (GPa)
OL6/0.16	6	0.16	○	2000	200
FF30L6	30	2 x 0.03	▭	2000	140

2.2 Manufacturing of specimens and testing procedure

Specimens were made from self-compacting concrete. The concrete mix is presented in **Tab. 3**. In manufacturing the concrete mix, portland cement, natural sand, coarse aggregate and crushed limestone were used. A plasticizer was also added to concrete mix to produce a uniform and homogeneous mix. The mixing procedure is as follows:

- Mix dry components (cement, sand, coarse aggregate and crushed limestone) for 2 to 3 minutes.
- Add steel fiber by hand, mix for 8 minutes.
- Add 2/3 of water volume, mix for 2 minutes.
- Add plasticizer Stachement, mix for 2 minutes.
- Add the remaining water volume, mix for 2 minutes.

The fresh concrete was then poured into moulds and vibrated for 5 seconds. Cube specimens of 150 mm dimensions were used to determine the compressive and splitting strength of concrete, which were measured based on an average of twelve or for samples. All specimens were cast and cured under similar conditions and tested after 28 days.

Tab.3 Concrete mixture

Materials	Quantity per 1 m^3	
	Plain concrete	SFRC
Cement 42.5 R (kg)	460	
Crushed limestone (kg)	120	
Sand 0-4 mm (kg)	1000	
Coarse aggregate 4-8 mm (kg)	600	
Plasticizer Stachement (l)	4.3	
Water (l)	186	237
	w/c = 0.4	w/c = 0.51

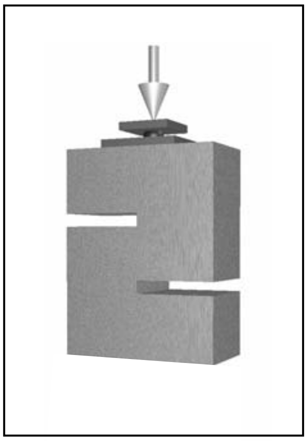


Fig. 2 Test arrangement

The specimens were loaded by a 500 kN hydraulic testing machine with loading control. Loading rate was approximately 18 kN/min according to [2]. Details of test arrangement are shown in **Fig. 2**.

3 Experimental results

3.1 Shear failure of specimens

Most of fiber concrete specimens failed in a shear along the shear plane with a gradual process of crack development (**Fig. 3**). Failure mode of specimens without fibers was very brittle with no warning before collapse. The specimens failed suddenly within 1 to 2 seconds after initiation of the first crack. Some specimens lost their integrity and broke into several pieces.

a) b) c)

Fig. 3 Specimen shear failure: a) shear crack initiation, b) collapse of specimen, c) failure surfaces

3.2 Test results - discussion

The results obtained are summarized in **Tab. 4**. Both, the maximum shear stress τ_{max} and the cracking shear stress τ_{cr} are calculated for each specimens tested. The shear stress was obtained by dividing the applied load by the shear area.

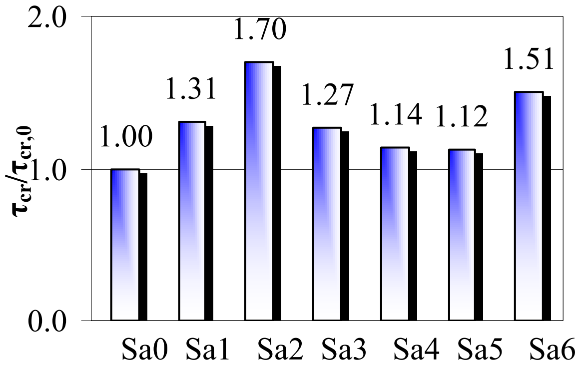
The results show clearly that fibers significantly increase the cracking and maximum shear stresses of the specimens, which increase with increasing of fiber amounts. The increase obtained in the cracking shear stress of the specimens contained fibers compared to the specimens without fibers ranged from 12 to 70 %, while the increase obtained in the maximum shear stress was 17 up to 76 % (**Fig. 4**).

Using fiber combination increases significantly the specimen shear stresses. The most effective fiber combination is that contained a combination of 60 kg/m^3 of fibers OL and 30 kg/m^3 of fibers FF (series Sa6). This fiber combination provides a high increase of the shear stresses which was 51% in the cracking shear stress and 57% in the maximum shear stress. Moreover, in comparison with the other series which contained only fibers OL (Sa1) or fibers FF (Sa3), but with the same fiber amounts (90 kg/m^3), this fiber combination give the greatest increase in the shear stresses (**Fig. 4**).

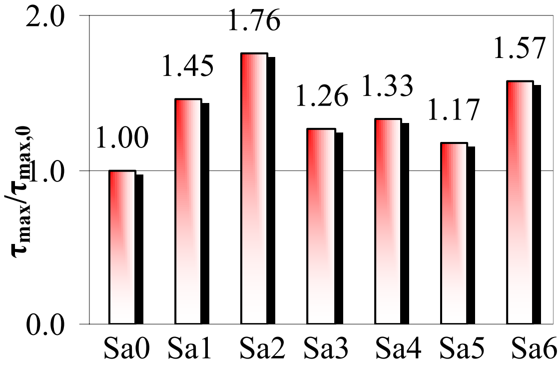
For specimens with fiber amount of 90 kg/m^3, the results also show that specimens, which contained fibers OL (Sa1) have greater increase of the cracking and maximum shear stresses (31% and 45%) than specimens that contained fibers FF (27% and 26%) (Sa3).

Tab. 4 Experimental results (an average value of 12 or 3 tests)

Specimens	Fiber volume (kg/m^3)		$f_{c,cube}$ (MPa)	$f_{sp.cube}$ (MPa)	P_{max} (kN)	P_{cr} (kN)	τ_{max} (MPa)	τ_{cr} (MPa)
	OL	FF						
Sa0	-	-	60.12	3.20	83.54	73.75	5.57	4.92
Sa1	90	-	-	3.72	134.75	96.25	8.98	6.42
Sa2	120	-	-	4.73	146.75	125.25	9.78	8.35
Sa3	-	90	-	3.42	105.25	93.33	7.02	6.22
Sa4	45	45	-	3.55	111.00	82.75	7.40	5.52
Sa5	30	60	-	3.56	97.75	84.00	6.52	5.60
Sa6	60	30	-	4.03	131.00	111.00	8.73	7.40



a)



b)

Fig. 4 The ratio of shear stress of specimens contained fiber to specimens without fibers: a) cracking shear stress τ_{cr}, **b**) maximum shear stress τ_{max}

The ratio of the maximum splitting stress of specimens contained fibers to specimens without fibers is shown in **Fig. 5**. For specimen series with fiber amount of 90 kg/m^3, the series with fiber combination give relative higher increase compared to the increase of specimens contained individual fiber type. The greatest increase observed for series with fiber combination was 26% (Sa6), while the greatest increase obtained for series with individual fiber type was 16%.

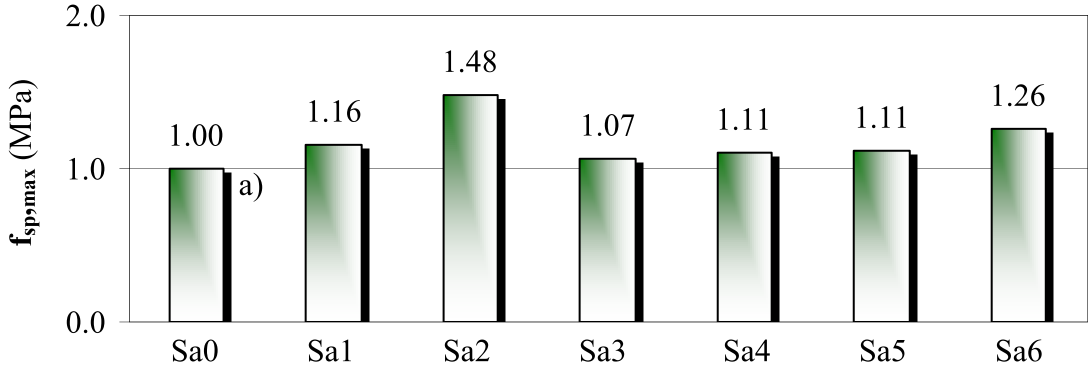


Fig. 5 The ratio of maximum splitting stress of specimens contained fibers to specimens without fibers

4 Conclusions

The test results obtained show that fibers OL are very effective in increasing the shear strength as well as the splitting strength of concrete. The increase of shear strength was up to 45 % (90 kg/m^3 OL) and in the splitting strength was up to 48 % (90 kg/m^3 OL) compared to specimens without fibers. The concrete strengths increase with increasing of fiber amounts. Fibers FF are less effective than fibers OL. The maximum increase in the shear strength of the specimens contained fibers FF30L6 was 26 % (Sa3). From the point of view of the splitting strength, fibers FF produce a negligible increase of 7% (Sa3).

The test results confirmed high effectiveness of using fiber combinations to improve the strength of concrete in comparison with specimens contained individual fiber type. The most effective fiber combination contains 60 kg/m^3 of fiber OL and 30 kg/m^3 of fibers FF. The specimens with this fiber combination had significant increase in the shear strength and splitting strength (57% and 26%) compared to the specimens without fibers.

The less ineffectiveness of fibers FF (in comparison with fiber OL) in the increase of concrete shear strength could be related to their flexural stiffness that was relative very small and this fact effects evidently in a negative way to distribution and orientation of them in concrete matrix.

Acknowledgements

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