ANALYSIS OF DIFFERENCES IN THE BEHAVIOUR OF TRADITIONAL AND SELF-COMPACTING STEEL FIBRE REINFORCED CONCRETE

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Abstract

Many studies have been conducted in past decades in order to promote the application of steel fibre reinforced concrete (SFRC), either traditional or self-compacting. However, just a few of them focus on explaining the differences in the behaviour and the properties of these two types of concrete. The objective of this paper is to analyse such differences in terms of flexural behaviour, fibre content and orientation. For that, an extensive experimental programme was conducted. In total 3 mixes of self-compacting and 3 mixes with traditional concrete were produced with the nominal fibre contents of 30kg/m^3, 45kg/m^3 and 60kg/m^3. In each case, specimens were cast and characterized with the Bending Test (code EN 14651) and the Inductive test. The results show how fibre orientation justifies the differences in the mechanical behaviour of the materials and the scatter of the results.

Keywords: SFRC, SFRSCC, bending test, inductive test, fibre orientation

1. Introduction

Many studies have been performed in the past decades in order to promote the application of steel fibre reinforced concrete (SFRC), either traditional or self-compacting.[1] [2] SFRC has notable advances such as remove rebars totally or partially from concrete, increase the energy absorption capacity and toughness of the material as well increase tensile and flexural strength of concrete. At initial stage, researchers paid more attention to study the different elements of traditional steel fibre reinforced concrete (SFRC). However, with the reduction of skilled workers it was more and more difficult to produce good structural elements to meet the requirements of clients. In order to resolve this thorny issue, self-compacting concrete (SCC) appeared in 1988 invented by K. Ozawa.[3] Due to the notable advantages such as reduce construction period, decrease noise pollution and improve economic benefits; a lot research work has been devoted over the last decade to

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make self-compacting concrete more robust By adding steel fibres into SCC can not only have the merits of SCC but also could combine the advantages of SFRC. Research on steel fibre reinforced self-compacting concrete (SFRSCC) has been highlighted since it was first put into use in real structural elements.[4] [5]

In order to guarantee the quality of SFRC, to characterize the post-cracking behaviour and to evaluate the fibre content are very significant. Generally, the characterization of post-cracking residual tensile strength is usually performed through three point or four point bending test. On the other hand, the fibre content is estimated according to the UNE-EN 14721:2006. For that, specimens must be either crushed or fresh concrete should be washed in order to separate the fibres that are then weighted. Using this destructive method, it is not only waste time but also uneconomical. In addition, limited number of tests performed per day compromise both the statistical representativeness of the results and the effectiveness of the quality control system.

In the present paper, firstly, study on SFRC and SFRSCC by three point bending test to characterize and compare the post-cracking behaviour will be presented. Then non-destructive test “inductive test” would be carried out on cubic samples, which are extracted from prismatic specimens, to assess the fibre content and orientation within the specimens. Finally, further analysis of post-cracking behaviour according to bending and inductive test will give an objective evaluation for using SFRC, either traditional or self-compacting.

2. Materials

Table 1 presents the composition of the mixes tested in the experimental campaign. Hook-ended BASF MASTERFIBRE 502 steel fibres were used for the preparation of specimens. The main characteristic of the fibre are shown in Table 2.

Tab.1: Mix composition of traditional SFRC and SFRSCC (in kg/m^3)

Mixtures	SFRC	SFRSCC
Sand 0/5	817	1200
Fine Aggregate 5/15	404	500
Coarse Ag gregate 12/20	810	200
Water	156	165
CEM I 52.5 R UNILAND	312	380
Super-plasticizer Glenium TC 1425	2.19	4.56
XSEED (Early strength admixture)	6.24	7.6

Tab.2: Characteristics of steel fibre

Tensile strength	Min. 1000 N/mm^2
Length	50 ± 1 mm
Diameter	1.0 mm ± 0.1 mm
Aspect ratio	50
Number of fibres per kg	3000

3. Experimental study

3.1 Specimens

Batches of concrete with the fibre content of 30 kg/m^3, 45 kg/ m^3 and 60 kg/ m^3 were cast in the prepared concrete company PROMSA both for SFRC (numbered SFRC-30, SFRC-45, SFRC-60) and SFRSCC (numbered SFRSCC-30, SFRSCC-45, SFRSCC-60). For each batch of concrete, three specimens were prepared Abrams cone test according to UNE 83503 for SFRC was conducted at fresh state. Likewise, the slump flow test according to EN 206 in the case of SFRSCC was performed as well. The fresh state result of all mixes met the requirements established.

All the specimens were demoulded 48 hours after casting. Then, they were stored at the temperature of 20°C ± 1 °C and relative humidity ⩾ 95% until the preparation for testing.

3.2 Tests

Compressive strength tests, at 1, 7 and 28 days, were conducted in PROMSA in accordance with EN 12390 3:2009. Moreover, three point bending tests were performed in the laboratory of Tecnologia de Esctructuras, Luis Agulló, Universitat Politecnica de Catalunya (UPC) following the EN 14651. Afterwards, inductive test was performed in cubic samples which are extracted from prismatic specimens.

3.2.1 Bending Test

This test was performed on prismatic specimens with the dimension of 550 × 150 × 150 mm at the age of 28 days. All the experimental process was carried out in accordance with EN 14651.

3.2.2 Inductive test

The Inductive test was developed by the research group at the UPC to assess the fibre content and orientation within the specimen. The description of the methodology was detailed in Torrents.[6] In this experimental programme, cubic samples were extracted from prismatic specimens after the bending test as indicated in Figure 1 (a). Afterwards, the specimen was put into the measuring cell. The test-set-up may be seen at Figure 1 (b).

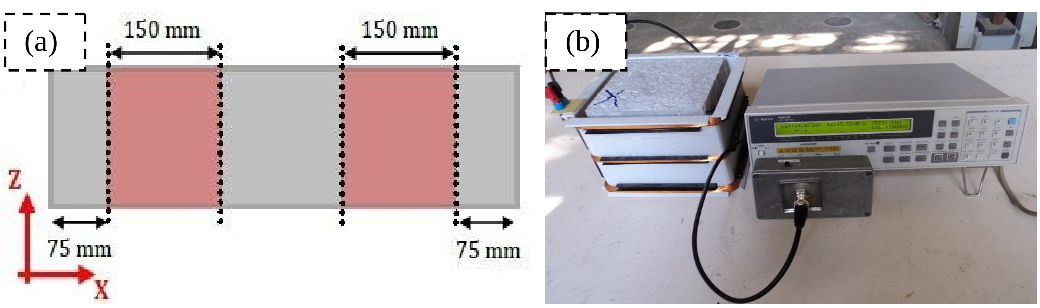

Fig. 1: (a)Extracted cubic sample and (b) Test set-up for inductive test

In order to calibrate the results, four samples were crushed as well as weighted the fibres contained within. This was done by first compressing the specimens to complete failure. The chunks were then fed into a grinding machine. Once the specimens were reduced to rubble, they were sifted through with a magnet to retrieve all the fibres.

4. Results and analysis

4.1 Compression Test

Table 3 shows the average compressive strength at 1, 7 and 28 days. It can be seen that there is no significant difference for either SFRC or SFRSCC in terms of compression test comparing at same age. It also can be explained that by adding fibres into the matrix has no significant effect on the result of concrete compressive strength.

Tab.3: Compression Test Results (in MPa)

Days	Traditional SFRC	SFRSCC
1	20.43	20.23
7	54.67	54.80
28	64.63	67.43

4.2 Bending Test

Curves in Figure 2 present the load- crack mouth opening displacement (CMOD) relationship for each mix as the mean value of three specimens. The main data obtained from the three point bending test to characterize the post-cracking behaviour of concrete is presented in Table 4.

Generally speaking, the load decreases as the CMOD increases after the limit of proportionality (LOP) except the curve SFRSCC-60. In addition, the residual load for the same CMOD increases with the fibre content in all cases. Moreover, the post-cracking behaviour for SFRSCC show higher value than SFRC, either in terms of LOP or the residual strength.

Specifically, compare series SFRC-30 and SFRSCC-30, which has the same fibre content, it may be observed that the LOP and $f_{R,1}$ for series SFRC-30 are slightly bigger than that of SFRSCC-30. However, the residual strength for series SFRC-30 is higher than series SFRSCC-30 after the CMOD=1.5, which are more representable in terms of ultimate limit state condition. More interesting, the residual strength $f_{R,4}$ for series SFRSCC-60 is even bigger than the LOP, which could be due to the high fibre content, the good bond condition between aggregates and steel fibres as well more fibre align parallel to the bottom plane.

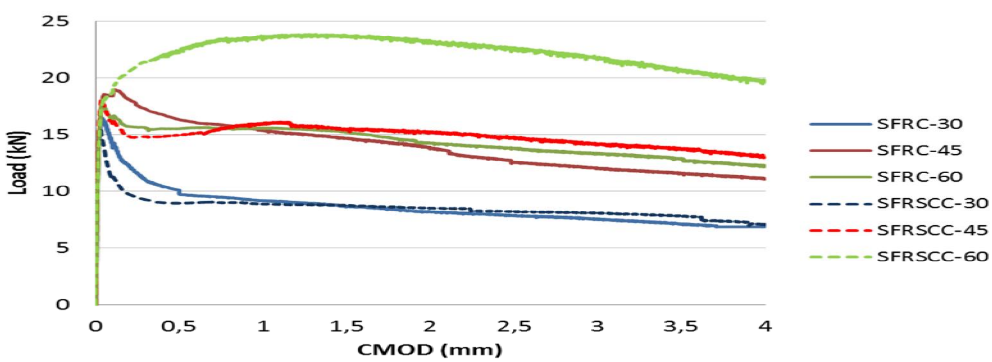

Fig. 2: Load-CMOD relationship curves

Tab.4: Main data obtained from the three point bending test(in MPa)

Series	LOP	$f_{R,1}$	$f_{R,2}$	$f_{R,3}$	$f_{R,4}$
SFRC-30	5.17	3.15	2.70	2.44	2.22
SFRC-45	5.76	5.06	4.54	3.89	3.60
SFRC-60	5.49	4.81	4.71	4.26	4.00
SFRSCC-30	4.99	2.85	2.79	2.61	2.47
SFRSCC-45	5.80	4.72	4.86	4.67	4.33
SFRSCC-60	5.89	7.13	7.54	7.12	6.41

4.3 Inductive test

The inductance variations and percentage of the samples in each axis are shown in Table 5. It shall be noted that the Z axis correspond to the pouring direction, while the Y axis is perpendicular to the cut face of the specimen. By using the mean inductance values, it is possible to calculate the fibre content, Cf, as shown in Figure 3.

Tab.5: Inductance variation and inductance percentage in each axis

Samples	Inductance (mH)			Inductance percentage		
	X	Y	Z	X	Y	Z
SFRC-30	22.1	32.63	10.93	33.66%	49.70%	16,65%
SFRC-45	32.48	45.9	15.92	34.44%	48.67%	16.88%
SFRC-60	43.15	62.72	20.93	34.03%	49.46%	16.51%
SFRSCC-30	20.02	28.12	10.07	34.39%	48.31%	17.3%
SFRSCC-45	26.4	54.95	13.82	27.74%	57.74%	14.52%
SFRSCC-60	39.22	71.32	19.87	30.07%	54.69%	15.24%

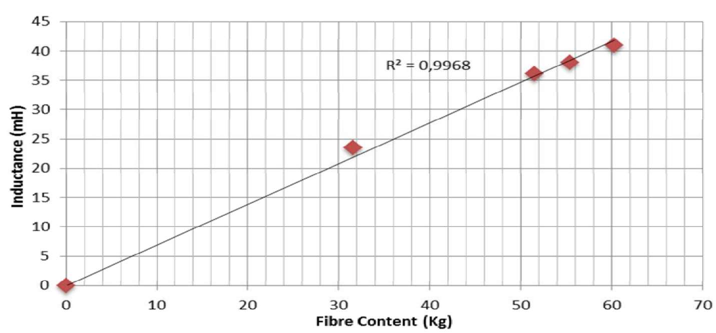

Fig. 3: Inductance-Fibre Content relationship curves

Table 5 indicates that the highest amount of fibre is orientated along the Y-axis whereas the smallest one is along the Z-axis. Such outcome is reasonable, since fibres tend to align parallel to the bottom of the mould; the wall effect as well as the flow direction of concrete also lead to the results. [7][8]

Additionally, fibres align parallel to Y axis in SFRSCC specimens are slightly higher than that of in SFRC. This may due to the high flowability of SFRSCC and the effect of vibration on SFRC. The high R^2 (0.9968) in Figure 3 illustrates that it is possible to predict the amount of fibres with the inductance results.

Combining the results shown in Figure 2 and Table 6, it may be easy to know that the residual strength of concrete is proportional to the inductive test results. This conclusion would be useful in the application of evaluating the post-crack behaviour of SFRC.

5. Conclusions

The following con conclusion may be drawn from this research programme:

- The LOP and residual tensile strength are proportional to the fibre content for SFRC and SFRSCC.
- With the same fibre content, the residual tensile strength for SFRSCC is higher than SFRC.
- The load-CMOD curves and inductive test results indicate that a more uniform distribution of steel fibres appear in SFRSCC if compared with SFRC.
- The inductive test is capable of detecting differences in the fibre content.
- By using inductive test result can predict the post-cracking behaviour of SFRC.

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References

[1] J. I. Daniel, S. H. Ahmad, "State-of-the-Art Report on Fiber Reinforced Concrete Reported by ACI Committee 544," vol. 96, no. Reapproved, 2002.

[2] F. de Larrard and T. Sedran, "Mixture-proportioning of high-performance concrete," *Cement and Concrete Research*, vol. 32, no. 11, pp. 1699–1704, Nov. 2002.

[3] H. Okamura and M. Ouchi, "Self-Compacting Concrete," *Journal of Advanced Concrete Technology*, vol. 1, no. 1, pp. 5–15, 2003.

[4] L. Ferrara, Y.-D. Park, and S. P. Shah, "A method for mix-design of fiber-reinforced self-compacting concrete," *Cement and Concrete Research*, vol. 37, no. 6, pp. 957–971, Jun. 2007.

[5] B. Akcay and M. A. Tasdemir, "Mechanical behaviour and fibre dispersion of hybrid steel fibre reinforced self-compacting concrete," *Construction and Building Materials*, vol. 28, no. 1, pp. 287–293, Mar. 2012.

[6] J. M. Torrents, A. Blanco, P. Pujadas, A. Aguado, "Inductive method for assessing the amount and orientation of steel fibers in concrete," *Materials and Structures*, vol. 45, no. 10, pp. 1577–1592, Apr. 2012.

[7] D. Dupont, *M ODELLING AND EXPERIMENTAL VALIDATION OF*. 2003.

[8] S. GRUNEWALD, *Performance-based design of self-compacting fibre reinforced concrete*.ISB: 9040724873. 2004.