Toughness properties and fiber dispersion in vibrated and self-consolidating fiber reinforced concrete

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ABSTRACT: The connections between mechanical properties of fiber reinforced concrete and fiber dispersion, as influenced by fresh state properties of the material and casting modalities, are investigated in this work with reference to mostly two-dimensional structural geometry, selected as representative of significant potential applications in precast construction industry (folded plate roof elements, structural topping in precast slabs etc.). Square plates 600 mm wide and 60 mm thick were cast with three different fiber reinforced concretes featured by different fresh state properties. Specimens were cast in different ways, allowing for either a radial spreading or a prevalent one-directional flow of the fresh mix in the moulds. After analyzing fiber dispersion through Alternate-Current Impedance Spectroscopy, beam specimens have been cut from the plates with their axis differently oriented with respect to the flow direction, and tested in 4 point bending, either according and upside-down with respect to the casting. The thus measured mechanical properties are going to be correlated to the detected fiber dispersion.

1 INTRODUCTION

The benefits of incorporating (steel) fibers in concrete and other cement based materials have been widely investigated over the past forty years (Shah et al., 2004) leading to the current thorough knowledge of the multifold behavior of Fiber Reinforced Concrete (FRC). Nevertheless structural applications have not followed a similar development trend, only in the very last years the use of FRC having been extended from partially load-carrying structures, such as pavements, facade and wall panels, to more demanding structural elements e.g. precast roof elements (di Prisco M. & Plizzari, 2004), tunnel linings (Falkner & Henke, 2004; Gettu, 2004) and girders for slope stabilization (di Prisco C. et al., 2006). The partial substitution of conventional reinforcement with fibers, or even its complete replacement, such as for transverse shear reinforcement, represents a surely attractive characteristics of this material from the point of view of (precast) construction industry.

The effectiveness of what above said relies, more or less explicitly, on the assumption of a uniform dispersion of fibers within the elements, since poor dispersion may lead to poor fresh and hardened state properties, thus affecting the resulting structural performance (Ferrara & Meda, 2006). Fiber dispersion related issues hence stand as a crucial point to be tackled for a wide promotion of safe and reliable structural applications of FRCs. Various techniques have been developed and assessed for non destructive and time effective monitoring of fiber dispersion (Franchois et al., 2004; Ozyurt et al., 2006a,b).

The use of self consolidating concrete may be helpful at guaranteeing a more uniform dispersion of fibers, thanks to both its self placeability, which lead to the elimination of compaction by vibration, and rheological stability in the fresh state. The possibility of even driving, through a suitable balance of fresh state properties, the orientation of fibers along the anticipated stress pattern within the element when in service, e.g. under dead and long term live loads, may represent an interesting opportunity to be exploited. The compactness of the SCC matrix, due to the higher amount of fine and extra-fine particles, may improve interface zone properties (Corinaldesi & Moriconi, 2004), and consequently also the fiber-matrix bond, leading to enhanced post-cracking toughness and energy absorption capacity. The synergy between self compacting and fiber reinforced technologies, thanks to the elimination of vibration and the reduction or even the complete substitution

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of conventional reinforcement with fibers, is likely to improve the economic efficiency of the construction process. Increased speed of construction, reduction or suitably focused rearrangement of labor resources, costs and energy consumption, better working environment, with reduced noise and health hazards, also contribute toward the automation and reliability of quality control.

In this work, toughness properties of steel fiber reinforced concrete are investigated into a multifaceted framework, aiming at establishing connections with fresh state properties and fiber dispersion related issues. Three fiber reinforced concrete mixes were designed for different fresh state properties (vibrated, self consolidating and highly fluid and hence prone to segregation) and three square plates 600 mm wide and 60 mm thick were cast for the self consolidating and segregating mixes, while two were cast for vibrated concrete. For self consolidating steel fiber reinforced concrete - SCSFRC - and segregating SFRC, plates were cast either from the center of the formwork, allowing a radial spread of fresh concrete, and from one side, an almost unidirectional flow of the fluid mixture filling the moulds in this case. After non destructive measurement of fiber dispersion through Alternate Current Impedance Spectroscopy, AC-IS, the plates were cut into five beams 120 mm wide, to be tested in 4-point bending. For plates cast from the side, beams were cut with their longitudinal axis either parallel or vertical to the casting flow direction.

The material performance in the hardened state is strongly influenced by fresh state properties and fiber dispersion, which are on their hand dependant on each other. An attempt of assessing the above said correlations in the framework of an omni-comprehensive approach is performed in this study.

2 MIX DESIGN OF SFRCS AND FRESH STATE CHARACTERIZATION

The mix proportions of the three different steel fiber reinforced concrete investigated in this study are shown in Table 1. Cement type I-ASTM and class C fly ashes were employed, together with a polycarboxilate superplasticizer. In all cases fiber reinforcement consisted of hooked end steel fibers 35 mm long and with an aspect ratio equal to 65. Maximum aggregate diameter was equal to 10 mm. For vibrated SFRC the fresh state performance was characterized only by means of the slump test: a slump height loss equal to 210 mm was measured for both batches, each batch corresponding to one plate. In the other cases, the slump flow test was performed, measuring the final spread diameter and the time to reach a 500 mm spread, T_{50} (Table 2). A Visual Segregation Index - VSI, ranging from 0 to 3, respectively for very stable and loose mixes, (Khayat et al., 2000) was also assigned from the observation of the flown patty as an indicator of the stability of the mix.

As illustrated in detail in Ferrara et al. (2007a), the fresh state performance is related to an average spacing of solid particles, d_{ss}, which is an indicator of their degree of suspension in the fluid cement paste:

$$d_{ss} = d_{av}\left[\sqrt[3]{1+\frac{V_{paste} - V_{void}}{V_{concrete} - V_{paste}}} - 1\right] \qquad (1)$$

where V_{paste} is the volume of paste, V_{void} is the void ratio of the solid particle skeleton (aggregates and fibers), determined according to ASTM C29/29. The average diameter of solid particles, d_{av}, is computed from the grading of aggregates and fibers, these being handled as a further "aggregate fraction" with 100% passing fraction at an equivalent diameter, $d_{eq,fibers}$, calculated on the basis of the equivalence with respect to specific surface area:

$$d_{eq,fiber} = \frac{3\,L_f}{1+2\dfrac{L_f}{d_f}}\,\frac{\gamma_{fiber}}{\gamma_{aggregate}} \qquad (2)$$

with L_f and d_f fiber length and diameter, γ_{fiber} and $\gamma_{aggregate}$ specificy gravity of fibers and aggregates (average of coarse and fine) respectively.
For the fibers herein employed $d_{eq,fibers}$ = 2.37 mm and d_{av} = 3.54 mm, irrespective of the different mix proportions.

Table 1. Mix proportions of SFRCs and model parameters

	Vibrated	Self cons.	Segregating
Material	**kg/m^3**	**kg/m^3**	**kg/m^3**
Cement	355	400	440
Fly ash 1.3	132	148	164
Water	166	186	205
SP	24	27	30
Fine aggr.	975	918	861
Coarse aggr.	795	749	703
Fibers	50	50	50
	relevant data for mix-design model		
V_{paste}	0.33	0.37	0.41
V_{void}	0.23	0.23	0.23
d_{ss} (mm)	0.27	0.36	0.46

Table 2. Fresh state characterization of self consolidating and segregating SFRC

	Self cons.	Segregating
Slump flow diameter (mm)	630	775
	665	800
	650	760
T_{50} (sec)	4, 4, 3	2, 2, 1
VSI	1.5, 1.5, 1	3, 3, 3

The role of the average spacing of solid particles in justifying the fresh state performance is evident from the data in Tables 1 and 2: for the given grading of aggregates and fibers a higher value of d_{ss} corresponds to a more dilute suspension in the fluid cement paste and hence to a highly flowable concrete, whereas a tighter suspension (lower d_{ss}) yields a less workable concrete. As shown in Table 1, different values of d_{ss}, and hence different levels of fresh state performance, are obtained in this study increasing the past volume ratio, and correspondingly decreasing the volume ratio of aggregates.

3 NON DESTRUCTIVE MONITORING OF FIBER DISPERSION THROUGH AC-IS

Alternate Current Impedance Spectroscopy AC-IS is an electrical characterization technique to monitor characteristics of cement based materials (Peled et al., 2001) and, as recently shown, can be usefully employed to monitor dispersion of conductive fibers in concrete (Ozyurt et al., 2006a). It involves the application of an excitation voltage (1V in this study) over a certain range of frequencies (10 MHz-10 Hz in the present case, stepped down according to a log-scale) and the measurement of the magnitude and phase of the current.

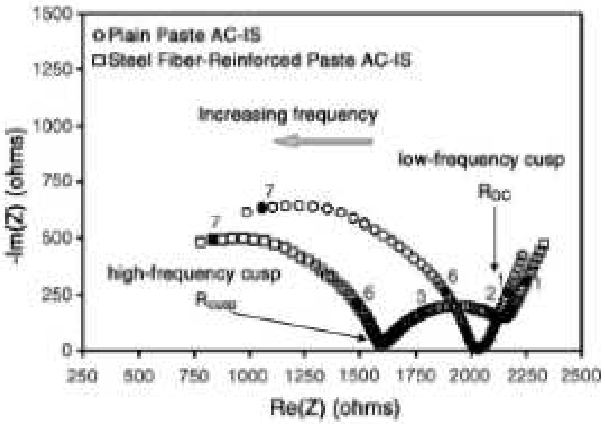


Figure 1: Sample Nyquist plot curves for plain and FRC cement paste (w/c = 0.40, fiber volume ratio = 0.35% - from Ozyurt et al., 2006a)

When the obtained data are converted into the real and imaginary part of the impedance Z and presented on the so-called Nyquist plot (-Im(Z) vs. Re(Z)) the so-called dual-arc behavior occurs (Figure 1) due to the frequency dependent behavior of conductive fibers. They are insulating under direct current (DC) and low frequencies of AC, because of, a thin oxide film that forms at the fiber-electrolyte interface, whereas they are conductive under high frequencies of AC. The low-frequency that can be detected on the Nyquist plot hence corresponds the resistance of the matrix, R_m, whereas the leftmost cusp represents the one of the composite, R. The following relationship holds for highly conductive fibers, for which the ratio of the fiber conductivity to the matrix conductivity can be considered infinite (see Ozyurt et al. 2006b for theoretical framework):

$$\frac{R_m}{R} = \frac{\sigma}{\sigma_m} = 1 + [\sigma]_{fibers}\ V_{fibers} \quad (3)$$

where σ and σ_m represent the conductivity (inverse of resistance) of the composite and of the matrix respectively, $[\sigma]_{fibers}$ is the intrinsic conductivity of the fibers and V_{fibers} is the fiber volume ratio (0.64% in the present investigation). The conductivity of the fibers can be calculated knowing only their aspect ratio $AR = L_f/d_f$.

$$[\sigma]_{fibers} = \frac{1}{3}\left[\frac{2(AR)^2}{3\ln(4AR)\ \text{-}7} + 4\right] \quad (4)$$

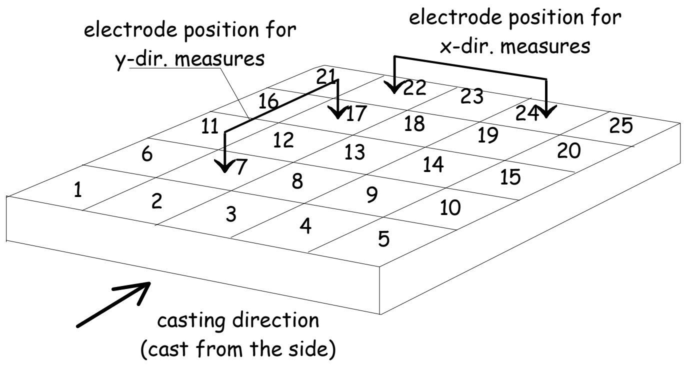


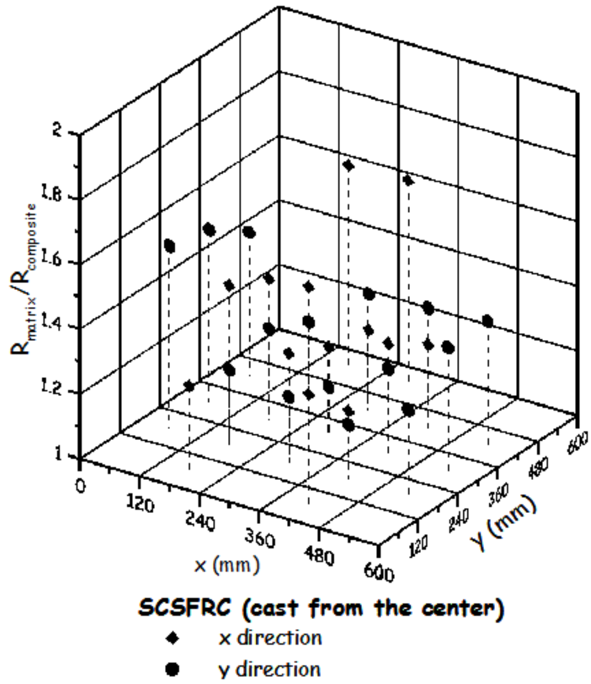
Figure 2: scheme for AC-IS measurements

The experimental set-up for the present investigation is shown in Figure 2. A grid has been drawn on the plate surface (actually the mould-finished one) consisting of 5x5 120 mm squares to locate measuring points. Stainless steel square plates (80 mm side) were employed as electrodes, constantly spaced at 240 mm; the electrical contact with the specimen surface (actually the mould finished surface) was guaranteed by means of same size (when wet) sponges, soaked in a 1M NaOH-KOH solution. The AC-IS measures were taken in both x and y direction, so to reproduce a real "in-situ" application, also when only one surface of the structural element is accessible and hence no "through thickness" information was obtained. Thirty AC-IS measures for each plate were taken, fifteen in each direction: for the nine central cells (7-9,12-14,17-19) it was possible to obtain information on fiber dispersion in both x and y direction, while for twelve edge cells information on either the x (2-4,22-24) or y (6,11,16,10,15,20) direction was gathered. No measure was taken for the four corner cells (1,5,21,25).

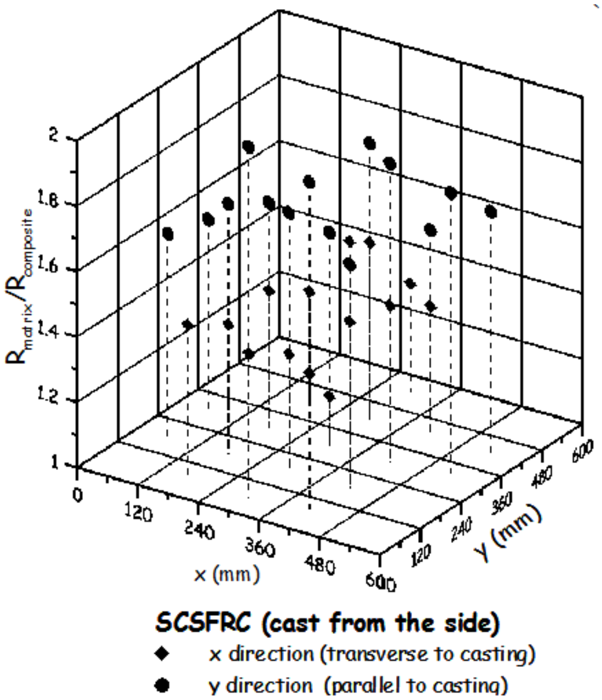
The average values and standard deviations of the matrix normalized conductivity $R_m/R = \sigma/\sigma_m$, in both x and y direction, and the related standard deviations are listed in Table 3. The measured values of the R_m/R ratio have also been plot for some representative situations. The influence of the fresh state properties of the concrete is evident also from this bulk information.

Table 3. Matrix normalized conductivity values

	σ/σ_m X direction	σ/σ_m Y direction
Specimen	average (std. dev)	average (std. dev.)
Vibrated FRC A	1.40 (0.22)	1.41 (0.27)
Vibrated FRC B	inconsistent results	
SCSFRC		
A-center cast	1.38 (0.14)	1.32 (0.13)
B – side cast	1.42 (0.11)	1.73 (0.13)
C – side cast	1.52 (0.15)	1.74 (0.19)
Segregating SFRC		
A – center cast	2.35 (0.55)	2.45 (0.69)
B – side cast	1.36 (0.22)	1.33 (0.19)
C – side cast	1.52 (0.23)	1.48 (0.20)



(a)



(b)

Figure 3: plots of matrix normalized conductivity for SCSFRC plates cast from the center (a) and from the side (b)

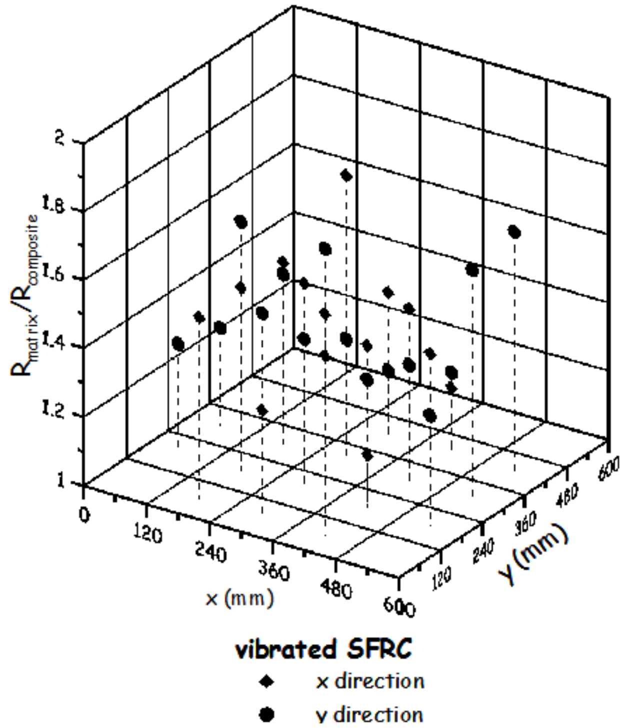


Figure 4: plots of matrix normalized conductivity for vibrated SFRC plate

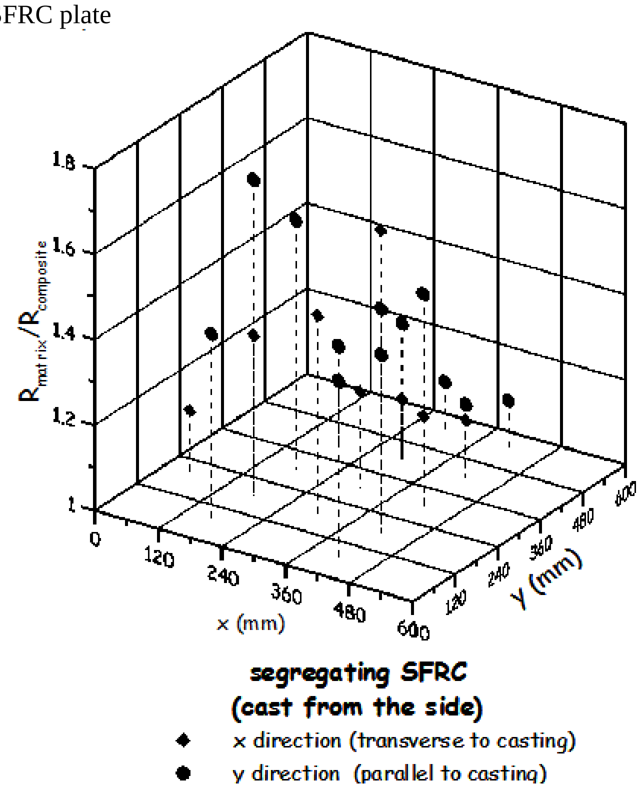


Figure 5: plots of matrix normalized conductivity for segregating SFRC plate cast from the side.

Self consolidating concrete is effective in guaranteeing a more uniform dispersion of fibers within the specimen, as well as in effectively driving their orientation along the casting direction (Figure 3a-b; for plates cast from the side the y direction is always the direction of casting), the exceptions along the edges of the center cast plate being consistently attributable to the boundary effect of the formwork.

Vibrated SFRC plates show, with respect to analogously cast SCSFRC ones, a dispersion of fibers almost twice as much scattered. The dispersion of matrix normalized conductivity values is shown, for the only plate which gave consistent measures, in Figure 4. The points are likely to be arranged according to a shape which resembles the filling modality of the moulds as driven by vibration, with peak values in the center and a radial decreasing spread, still with some exceptions along the edges, justified as above.

The same holds with reference to plates cast from the side with segregating SFRC (Figure 5), the strong decrease in the matrix normalized conductivity representing a significant impoverishment in the content of fibers along the flow direction. High scattering was detected also in these cases, whereas the effectiveness in governing the orientation of the fibers being lower than for SCSFRC due to the poor viscosity of fresh concrete. The measured high values of normalized matrix conductivity, with likewise high scattering, for segregating concrete plates cast from the center are, could be attributed to the strong segregation of fibers which may have affected the current path during AC-IS measures.

The issue of fiber orientation has been further investigated. From the measured values of the matrix normalized conductivities, the intrinsic conductivity of fibers in both x and y direction can be calculated:

$$[\sigma]_{fibers\ x,y} = \frac{\left(\dfrac{\sigma}{\sigma_m}\right)_{x,y} - 1}{V_{fibers}} \tag{5}$$

and then normalized to the sum of both to calculate a fractional effective conductivity

$$f_{fibers\ x,y} = \frac{[\sigma]_{fibers\ x,y}}{[\sigma]_{fibers\ x} + [\sigma]_{fibers\ y}} \tag{6}$$

Results, listed in Table 4, confirm the above said statement with reference to the possibility of effectively driving fiber orientation along the casting direction thanks to the suitably “selected” fresh state performance of the concrete. It has to be remarked, for the sake of clarity, that results in Table 3 have been obtained, for each direction, from all 15 AC-IS taken, whereas in Table 4 refer only to the nine central cells of the grid for which data in both x and y directions were gathered.

Since a linear correlation holds between the matrix normalized conductivity and the orientation number of fibers (Ozyurt et al., 2006a), the f_x/f_y ratio can be related to the ratio between orientation factors transverse and parallel to the casting direction. Results (Table 4) are consistent with recent findings by Ferrara et al. (2007 in press), which measured, through fiber counting, an orientation factor ratio equal to 0.56 with reference to SCSFRC plates, 500 mm wide and 1m long, cast parallel to the long side, the specimen geometry (width/length ratio) being likely to exert some influence.

Table 4. Fractional intrinsic conductivity of fibers

Specimen	f_x	f_y	f_x/f_y
Vibrated FRC A	0.50	0.50	1.0
Vibrated FRC B	inconsistent results		
SCSFRC			
A-center cast	0.56	0.44	1.27
B – side cast	0.37	0.63	0.59
C – side cast	0.40	0.60	0.67
Segregating			
A – center cast	0.52	0.48	1.08
B – side cast	0.39	0.61	0.64
C – side cast	0.44	0.55	0.8

4 TOUGHNESS PROPERTIES OF SFRC AND FIBER DISPERSION

In order to assess the connections existing between fresh state behavior, fiber dispersion and mechanical properties of SFRC in the hardened state, the 600 mm square plates were cut into five 120 mm wide beams, which were tested in 4point bending (loading span 128 mm). For plates cast from the side the beams were cut with their axis either parallel or transverse to the casting direction. Tests were performed in displacement control and the crack opening displacement across the midspan section at the beam intrados was measured (base length 150 mm). One of the beams, always cut from the same position inside the plate (4-24 for plates A and C and 16-20o for plates C - see Figure 2), was tested upside down with respect to casting, to check the influence of downward settlement of fibers, due, if any, to vibration of poor stability of the fresh concrete.

Results are shown, in terms of dimensionless load vs. COD in Figures 6-8, the current load value being normalized to the cracking load $P_{crack,}$ defined as the maximum load in the COD range 0-0.1 mm. Edge beams have not been considered, due to the boundary effect of formworks on fiber dispersion and hence on the measured mechanical properties.

For vibrated SFRC beams (Figure6) a quite high scattering affects experimental results, even for beams cut from the same plate; the downward settlement of fibers, due to vibration, justifies the worst performance of the beam tested upside down to casting, when compared to the one of companion beams cut from the same plate and tested according to it.

In the case of SCSFRC (Figure 7) results are, for beams cut from the same plate, fairly less scattered; a higher dispersion has been detected for beams cut from the center-cast plate. The effectiveness in avoiding the downward settlement of fibers is remarkable: results for beams tested upside down to casting are absolutely comparable with the ones of companion beams tested according to it. A certain sensitivity, even if lower than expectable, of the response to the relative orientation of the beam axis to the direction of casting, also appears. This may be justified considering that beams cut transverse to the direction of casting belonged to plate 3, for which a higher fractional conductivity in that direction was measured (Table 4).

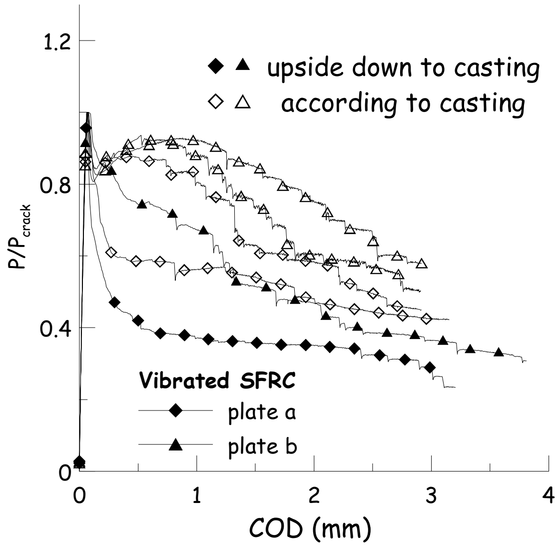


Figure 6: 4pb tests on vibrated SFRC beams – dimensionless load vs. crack opening displacement

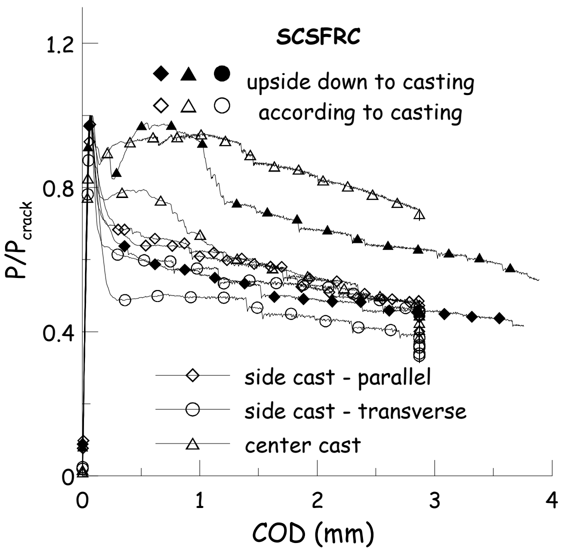


Figure 7: 4pb tests on self consolidating SFRC beams – dimensionless load vs. crack opening displacement

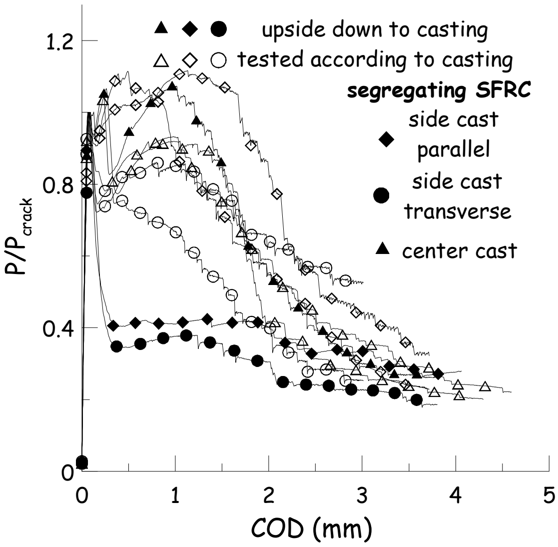


Figure 8: 4pb tests on segregating SFRC beams – dimensionless load vs. crack opening displacement

When the fluidity of the concrete is too high (Figure 8) the downward settlement of fibers yields to a remarkable difference between the performance of the beam tested upside down and according to casting, mainly for beams cut from the side-cast plates. A moderate post-cracking hardening is observed for beams tested according to casting, reasonably due to the higher concentration of fibers in the tension zone. The good performance of the beam cut from the centrally cast plate and tested upside down to casting can be attributed to a "late supply", during casting, of the fibers settled down in the mixing bowl right in the center of the specimen, i.e. in the zone where the crack is likely to form, which may have compensated the segregation of fibers themselves.

Table 5. First cracking strength, post cracking strengths and their ratios for beams tested in 4 point bending (beam 3 tested upside down to casting)

	f_{ctf}	$\sigma_{eq,I}$	$\sigma_{eq,II}$	$\sigma_{eq,I}/f_{ctf}$	$\sigma_{eq,I}/\sigma_{eq,II}$
Vibrated SFRC					
Plate A					
Beam 1	6.98	6.05	5.17	0.87	0.85
Beam 2	7.92	4.81	4.43	0.61	0.92
Beam 3	7.28	3.69	2.66	0.51	0.72
Plate B					
Beam 1	8.37	6.77	5.04	0.81	0.74
Beam 2	8.11	7.12	6.68	0.88	0.94
Beam 3	7.55	6.53	6.73	0.86	1.03
Self consolidating SFRC					
Plate A – cast from the center					
Beam 1	11.11	8.64	6.92	0.78	0.80
Beam 2	10.04	9.25	9.33	0.92	1.01
Beam 3	9.90	8.51	7.97	0.86	0.94
Plate B – cast from the side – parallel tested					
Beam 1	7.04	5.23	4.30	0.74	0.82
Beam 2	7.24	5.07	4.32	0.70	0.85
Beam 3	6.95	4.60	3.79	0.66	0.84
Plate C – cast from the side – transverse tested					
Beam 1	8.69	5.07	4.27	0.59	0.84
Beam 2	8.52	5.28	4.71	0.61	0.89
Beam 3	meaningless results				
Segregating SFRC					
Plate A – cast from the center					
Beam 1	8.62	8.24	7.77	0.96	0.94
Beam 2	8.44	6.64	7.07	0.79	1.06
Beam 3	8.88	7.60	8.84	0.87	1.16
Plate B – cast from the side – parallel tested					
Beam 1	8.15	8.60	8.96	1.06	1.04
Beam 2	8.78	8.78	7.16	1.00	0.82
Beam 3	7.08	3.30	2.95	0.46	0.90
Plate C – cast from the side – transverse tested					
Beam 1	8.02	5.96	6.61	0.74	1.11
Beam 2	8.53	6.66	5.15	0.78	0.77
Beam 3	7.50	2.64	2.77	0.35	1.05

Results of 4pb tests have been processed according to the prescriptions of the recently issued Italian guidelines for the design of SFRC structures (CNR-DT204). In Table 5 are listed for each beam:

- the first cracking strength f_{ctf}, calculated from the first cracking load, defined as above;
- the first equivalent post-cracking strength, $\sigma_{eq,I}$, averaged in the crack opening range 3-5 w_I, where w_I is the crack opening at first cracking;
- the second equivalent post-cracking strength, defined as the average stress in the crack opening range 0.8 w_u – 1.2 w_u, where w_u is assumed equal to 0.02 h, with h depth of the specimen (h = 60 mm, w_u = 1.2 mm in the present case).

The ratios $\sigma_{eq,I}/f_{ctf}$ and $\sigma_{eq,II}/\sigma_{eq,.I}$ can be assumed as toughness indicators, and will be thus referred to in the following. Data in Table 5 confirm what above said, qualitatively, from the observation of experimental curves.

The correlation existing between the mechanical performance of the composite and the dispersion of the fibers, as monitored through AC-IS and influenced by the fresh state performance of concrete, has been hereafter tentatively assessed also from the quantitative point of view. Data from beams tested upside down to casting have not been considered in this stage of the investigation. The toughness indicators are plot in Figure 9 vs. the normalized matrix conductivity in the direction of the beam axis, measured in the cell where fracture occurred during 4pb tests. Despite a common trend hardly could be found, both indicators are likely to increase with the matrix normalized conductivity,. A not clear trend of the $\sigma_{eq,I}/f_{ctf}$ ratio is observed for lower values of the matrix normalized conductivity; this deserves further investigation. For the $\sigma_{eq,II}/\sigma_{eq,I}$ ratio a reverse in the increasing trend is observed for matrix normalized conductivities higher than 1.7. These higher values correspond to segregating SFRC plates cast from the center: this may be due to the downward settlement of fibers, which alterates the the current pathin the AC-IS measures and also affects the mechanical performance of the composite.

In the literature more or less successful attempts of correlating the mechanical performance of the hardened fiber reinforced cement composites to an "average fiber spacing" have been found (Soroushian & Lee, 1990; Voigt et al., 2004). In this work, also consistently with the framework in which the mix-design and fresh state characterization was performed, the average spacing of solid particles d_{ss} [Eq (1)] has been chosen at the purpose (see also Ferrara et al., 2007 in press). The value of this parameter (Table 1) would correspond to a perfectly isotropic and uniformly dispersed case. To account for fiber dispersion and orientation it has been corrected through two factors:
- a dispersion factor, equal to the ratio between the average value of the matrix normalized conductivity parallel to the beam axis, measured for the whole plate (Table 3), and the one measured in the fracture cell in the same direction;
- an orientation factor equal to $0.5/f_{//}$, where $f_{//}$ is the fractional intrinsic conductivity [Eq.(6)]for the cell where fracture occurred in the direction of the beam axis (either f_y for plates A and C and f_x for plates C). The value 0.5 is to the fractional intrinsic conductivity for perfectly planar isotropic distribution of fibers in a 2D specimen

Both correction term takes into account that a higher concentration of fibers, furthermore better aligned along one direction, correspond to a tighter spacing.

For segregating SFRC the actual spacing of aggregates and fibers is tighter than the theoretical one. Visual observation showed that almost all fibers and coarser aggregates settled down in the half bottom part of the specimen: An attempt to consistently process also these data has been done herein, through a further rough correction factor equal to 0.5. As an exmaple the values of $\sigma_{eq,I}/f_{ctf}$ have been plot vs. the thus modified average spacing of solid particles, d_{ss}* (Figure 10).

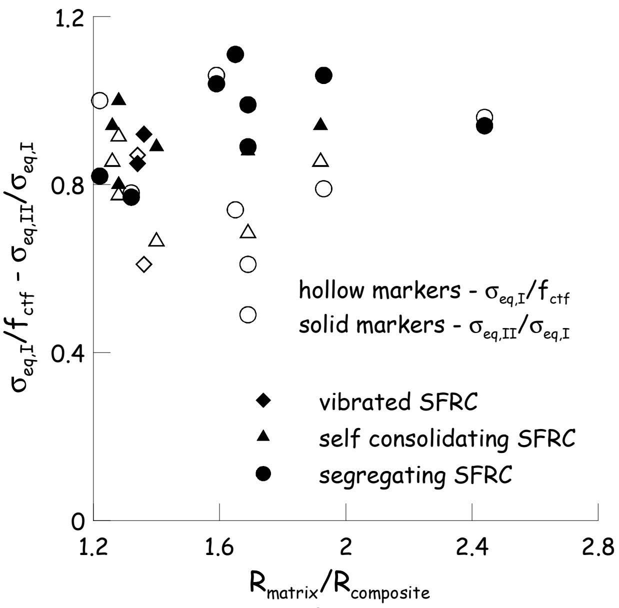


Figure 9: toughness indicators of SFRCs vs. matrix normalized conductivity

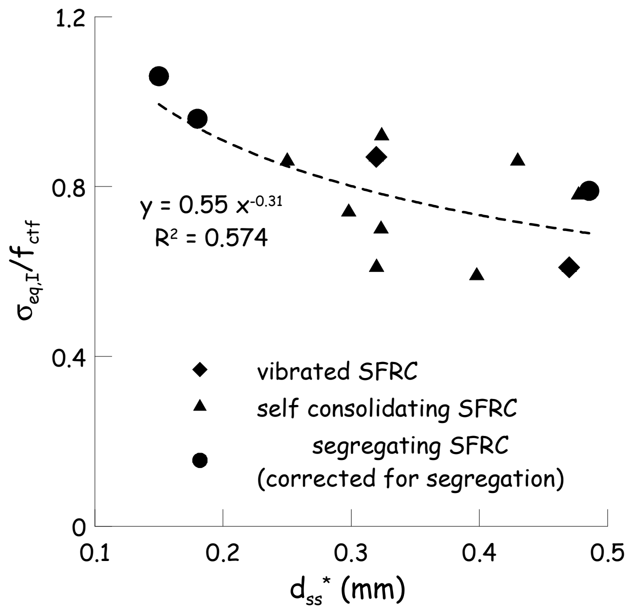


Figure 10: $\sigma_{eq,I}/f_{ctf}$ vs. average spacing of solid particles modified to take into account fiber dispersion and orientation.

The trend, despite the somewhat not excellent correlation, is consistent with the physics of the problem: a better mechanical performance of the composite corresponds to a tighter spaced fiber reinforcement. This can be achieved through the mix design and suitably balanced fresh state performance, leading to a more uniform and effectively oriented dispersion of fibers.

5 CONCLUSIONS AND FURTHER WORK

In this work the correlations between toughness properties of steel fiber reinforced concrete and fiber dispersion related issues, as influenced by the fresh state performance, have been investigated. A mix-design model recently proposed for SCSFRC has been employed to analyze the performance in the fresh state. It is based on an average spacing of the solid particles, which accounts for the grading of aggregates and fibers; these are regarded as an equivalent aggregate with respect to the specific surface area. The average spacing of solid particles, d_{ss}, is an indicator of the degree of suspension of the solid particles into the fluid cement paste.

The effectiveness of the self consolidating concrete in driving the orientation of fibers along the casting direction and in guaranteeing a uniform dispersion of the fibers, furthermore preventing their downward settlement, has been proved.

The performance of the composite in the hardened state, measured through 4 pb tests, has been shown to be strongly affected by the dispersion and orientation of fibers and have been tentatively correlated to the same parameter, d_{ss}, employed for mix design and fresh state characterization. A correction factor has been suitably defined to include in this parameter the effect of the dispersion and orientation of fibers, as influenced by the casting process, fresh state behavior of concrete and specimen geometry. The parameter d_{ss}, once modified as above, can be hence regarded also as an indicator of the binding efficacy of aggregates and fibers by the hardened cement paste.

Further investigation to improve the approach, including e.g. more explicitly the interaction of fibers with corase aggregates, and assess its reliability with reference to a broader range of cases is currently on going.

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