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On the orientation of fibres in structural members fabricated with self compacting fibre reinforced concrete

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ABSTRACT

The incorporation of fibres into concrete produces important benefits, mainly on the residual load-bearing capacity. These improvements depend on the type, content and orientation of the fibres, being a strong relationship between the number of fibres in the fracture surfaces and the post peak parameters. Although the fibres could be homogeneously distributed after mixing, the casting and compaction processes can significantly affect the fibre distribution and orientation, and consequently the mechanical performance of the material. In the case of Fibre Reinforced Self Compacting Concrete (FR-SCC) the existence of significant flow and wall effects may influence fibre orientation. This paper analyzes the fibre orientation in thin structural elements cast with FR-SCC and its effects on the residual mechanical properties. A slab of 0.90 × 1.80 × 0.09 m, a wall of 0.50 × 2.00 × 0.08 m, and a beam of 0.15 × 0.15 × 2.50 m were selected as representative elements where different concrete flow conditions take place. A strong heterogeneity in the orientation of the fibres was found. The fibre orientation varied with the flow rate and with the wall effect; the thickness of the elements or the proximity to the bottom of the moulds appeared as important variables. It was demonstrated that in thin elements the residual mechanical properties can be quite different when diverse zones and/or directions of the structural elements are considered.

1. Introduction

Nowadays it is well known that the benefits of adding fibres to concrete, mainly the improvements in the residual load-bearing capacity, are influenced by the type, content and orientation of the fibres. It was also proven that there is a strong relationship between the number of fibres in the fracture surfaces and the post peak parameters obtained in bending or in uniaxial tension tests [1–3].

Although the fibres may be homogeneously dispersed after mixing, the casting and compaction processes may affect the fibre orientation in the structural elements. In this sense, the use of Fibre Reinforced Self Compacting Concrete (FR-SCC) implies the analysis of new aspects especially when considering thin elements [4]. Several authors have recognized the existence of significant flow and wall effects in FR-SCC [5–7]. It was demonstrated that, as in conventional vibrated FRC, a 2D orientation appears in FR-SCC incorporating steel fibres [8].

A study [7] performed on 2 m long beams indicates that fibres align along the flow of fresh concrete. The influence of the fibre length on the fibre alignment is negligible and after a certain distance the fibre alignment no longer changes. Ferrara et al. [9] also show the effects of flow and their consequences on the anisotropy of the material behaviour which has to be taken into account regarding the used post peak parameters in structural design. At the same time, other work [10] performed on 4 × 5.3 m slabs with 0.10 m height draws attention on the possible distortions of fibre distribution due to the way in which concrete is poured, the workers actions and the wall effects.

A recent paper [8] discusses the influence of the casting procedure on the post peak behaviour of FR-SCC, considering steel and structural polymer fibres. It was concluded that the casting procedure can significantly affect the fibre distribution and orientation, and consequently the mechanical performance of the material. Important wall effects were found, that depend on the ratios between the dimensions of the mould and the length of the fibres. There are few references on the orientation of structural synthetic fibres in SCC. In this case, the differences in stiffness and density of the synthetic fibres can modify their distribution in structural elements when compared with steel fibres.

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The study and comprehension of the factors affecting fibre distribution and orientation in FR-SCC becomes very important in order to optimize the benefits of fibre reinforcement. The knowledge of the anisotropic behaviour produced by concrete flow can contribute to a better structural design, particularly regarding the use of post peak parameters. As a contribution, this paper presents experimental works performed with the aim of analyzing the orientation of fibres in different thin structural elements cast with FR-SCC. A slab, two walls and two 2.50 m long beams, were studied; the variation of fibre distribution and the consequent changes on the residual mechanical properties along these elements are discussed.

2. Experiences

2.1. Testing program and materials

Different prototypes were selected as representative elements where different concrete flow conditions take place: a slab of 0.90 × 1.80 × 0.09 m, a wall of 0.50 × 2.00 × 0.08 m, and a beam of 0.15 × 0.15 × 2.50 m.

The three kinds of prototypes were cast with FR-SCC incorporating 35 kg/m^3 (0.45% in volume) of hooked-end steel fibres 35 mm in length, 0.45 mm in diameter and an aspect ratio (l/d) equal to 78. The base concretes incorporated powder contents between 610 and 640 kg/m^3 (normal portland cement + calcareous filler), natural siliceous sand of 2.4 fineness modulus and granitic crushed stone of 12 mm maximum size as aggregates. A polycarboxylate based superplasticizer was also used. Fresh concretes achieved slump-flows between 670 and 700 mm and V-funnel times near 13 s. The 28-days compression strength ranged between 60 and 70 MPa.

In addition, two other FR-SCC were prepared to evaluate the effect of the fibre type. A wall with a concrete incorporating 3 kg/m^3 (0.3% in volume) of a synthetic macrofibre (polypropylene monofilament not fibrillated, 50 mm length), and a beam using a FR-SCC including 40 kg/m^3 (0.5% in volume) of a longer steel fibre (hooked-end fibre 50 mm length and aspect ratio 50) were cast. Base concretes were prepared with similar component materials.

As a reference, standard 0.15 × 0.15 × 0.60 m prisms were also cast.

2.2. Testing methods

Three-point bending tests were done measuring the load – CMOD response following the general guidelines of EN 14651-2005 [11]. The first crack load stress (f_L), the maximum stress (f_M, calculated from the maximum load obtained along the entire test), and the residual strengths f_{R1}, f_{R2}, f_{R3}, f_{R4} were calculated considering the post-cracking load capacity for 0.5, 1.5, 2.5 and 3.5 mm of CMOD.

To evaluate the fibre orientation along the prototypes and its effects on the mechanical parameters, beams were cut and tested as follows.

Prisms of 600 mm length were cut from the 2.5 m length beams. As indicated in EN 14651-2005 standard, a notch of 25 mm was sawn at the centre of the specimens; the used span was 500 mm.

In the case of the slab and the walls, the bending tests were performed on small specimens that were cut from each structural prototype. Giaccio et al. [12] found that using the same height/span and notch depth/height ratios there can be obtained the same residual strength parameters as those measured in standard beams by correcting the CMOD by the height beam ratio (h/150 mm). From the walls, specimens of 80 × 70 × 300 mm with a notch depth of 14 mm were sawn; they were tested with a 280 mm span. To evaluate the slab 90 × 70 × 320 mm prisms with a notch depth of 15 mm and a span of 300 mm were used. In both cases, beams from different zones and directions parallel and normal to concrete flow were studied.

Finally, after bending tests, the number of fibres on the fracture surfaces was counted to determine the density of fibres. In this way it will be possible to demonstrate that, as a consequence of the changes in fibres distribution, there can be significant variations of the mechanical response along a FR-SCC structural element, when different zones and orientations are considered.

2.3. Results and analysis

2.3.1. Steel fibre reinforced concrete slab

The slab was divided into three sectors (groups of beams) called I, II and III, where the flow and border conditions were different. Fig. 1 shows a schema of the beams extracted from the slab. Group I is affected by the pouring of concrete; group II has the highest flow rate and is only influenced by the lateral wall effect; finally in group III the end of the formwork affects the flow of the concrete.

Fig. 2 shows the stress–CMOD curves of the different specimens cut from the slab. Table 1 shows a summary of the strength parameters. The results are differentiated by group and beam orientation with respect to the flow direction (parallel or perpendicular); the mean, maximum, and minimum values are given. Variable post peak behaviours can be seen in beams IA, IB and IC, obtained from the zone where the concrete was poured. While beams IB and IA1

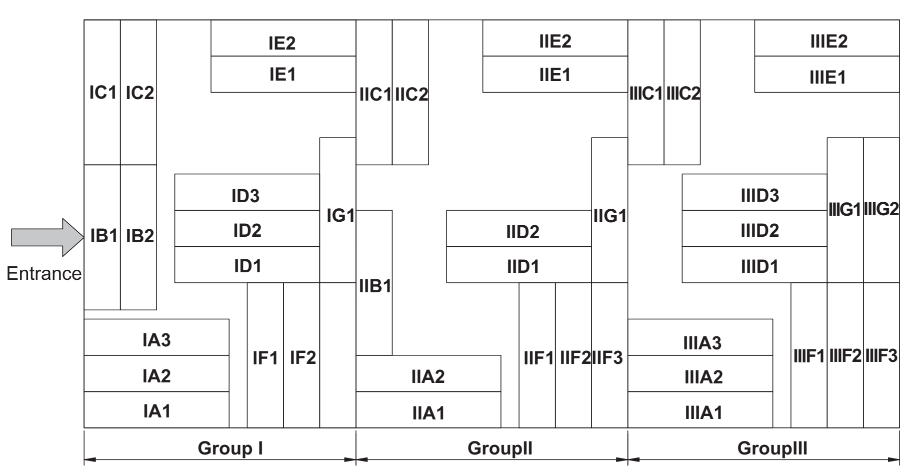

Fig. 1. Schema of the slab and the specimens obtained. FR-SCC incorporating steel fibres.

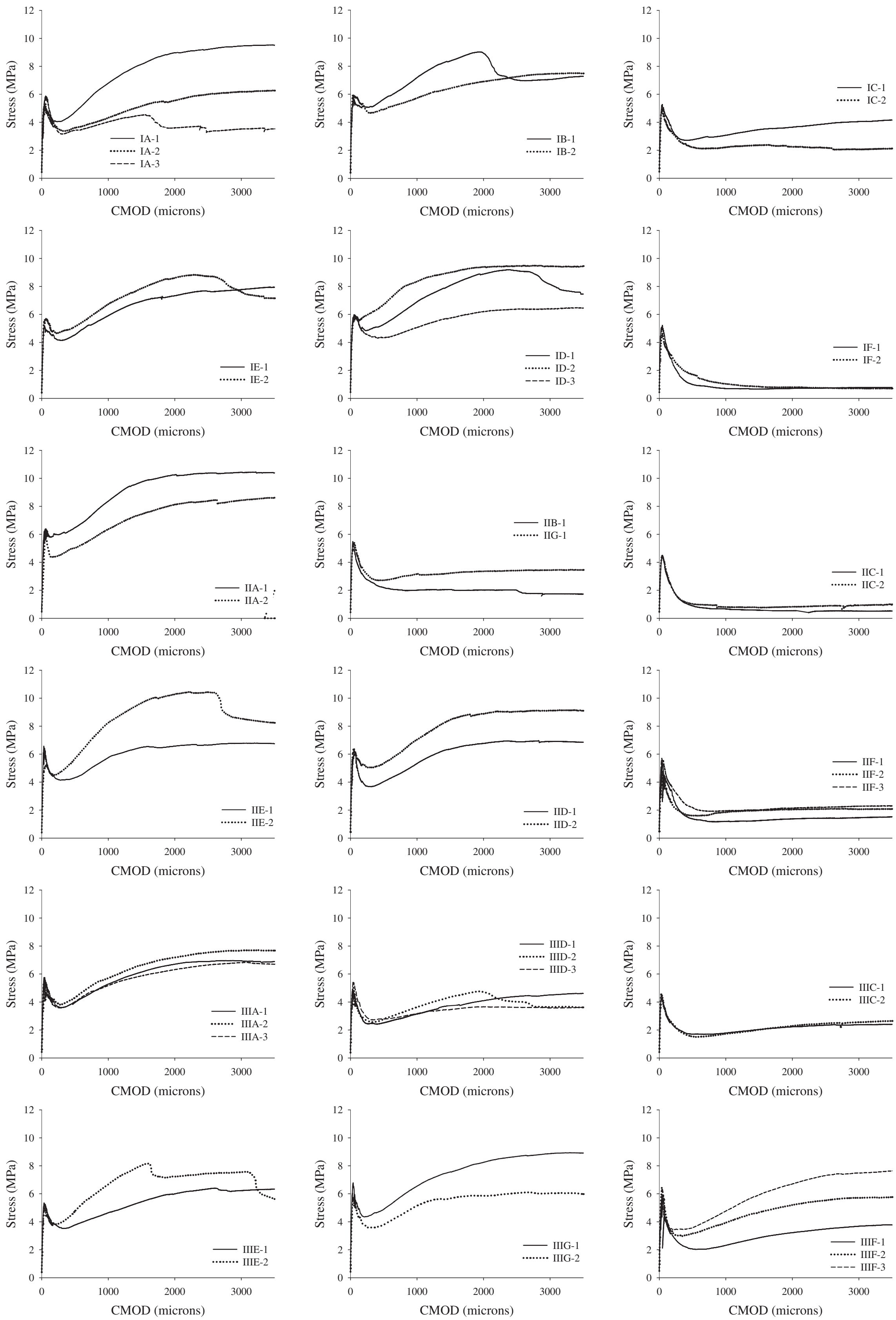

Fig. 2. Stress–CMOD curves of different specimens cut from the slab. FR-SCC incorporating steel fibres.

show a hardening type response, the opposite occurs in beams IA3 and IC. At the same time it can be seen that the beams closer to the formwork walls show a better response than their companion beams (IA1 > IA3, IB1 > IB2, IC1 > IC2), which is attributed to a better fibre alignment. Results from beams ID, IE and IF clearly makes evident the effect of fibre orientation produced by the concrete

Table 1
Slab prepared with steel FR-SCC. Summary of bending test results.

	f_L (MPa)	f_M (MPa)	f_{R1} (MPa)	f_{R2} (MPa)	f_{R3} (MPa)	f_{R4} (MPa)	Density (fibres/cm^2)
Sector I – parallel to flow direction							
Mean	**5.6**	**7.7**	**4.7**	**6.9**	**7.5**	**7.2**	**1.20**
Maximum	6.0	9.5	6.7	9.0	9.4	9.5	1.51
Minimum	5.2	5.2	3.4	4.5	3.3	3.5	0.85
SD	0.3	1.7	1.0	1.6	2.1	1.9	0.23
Sector I – perpendicular							
Mean	**5.2**	**5.9**	**2.8**	**3.2**	**3.2**	**3.3**	**0.74**
Maximum	6.0	9.0	5.7	8.4	7.2	7.5	1.45
Minimum	4.6	4.6	1.0	0.6	0.6	0.6	0.14
SD	0.5	1.6	1.8	3.1	2.9	3.1	0.53
Sector II – parallel to flow direction							
Mean	**5.6**	**8.4**	**5.2**	**7.8**	**8.3**	**8.1**	**1.59**
Maximum	6.6	10.5	6.5	9.7	10.4	10.4	2.27
Minimum	3.8	6.7	4.0	6.4	6.7	6.7	1.02
SD	1.0	1.6	0.9	1.5	1.6	1.3	0.37
Sector II – perpendicular							
Mean	**5.1**	**5.1**	**1.7**	**1.7**	**1.8**	**1.8**	**0.53**
Maximum	5.7	5.7	2.7	3.2	3.4	3.5	0.91
Minimum	4.5	4.5	0.9	0.6	0.5	0.5	0.28
SD	0.5	0.5	0.7	0.9	1.0	1.0	0.21
Sector III – parallel to flow direction							
Mean	**5.3**	**6.4**	**3.6**	**5.4**	**5.9**	**5.6**	**1.03**
Maximum	5.8	8.2	4.8	8.0	7.5	7.7	1.50
Minimum	4.9	4.9	2.5	3.5	3.6	3.6	0.82
SD	0.3	1.2	0.8	1.6	1.6	1.5	0.22
Sector III – perpendicular							
Mean	**5.6**	**6.3**	**3.0**	**4.4**	**5.1**	**5.3**	**1.08**
Maximum	6.8	8.9	4.9	7.6	8.7	8.9	1.60
Minimum	4.3	4.3	1.5	2.0	2.3	2.4	0.57
SD	0.9	1.6	1.2	2.1	2.4	2.5	0.35

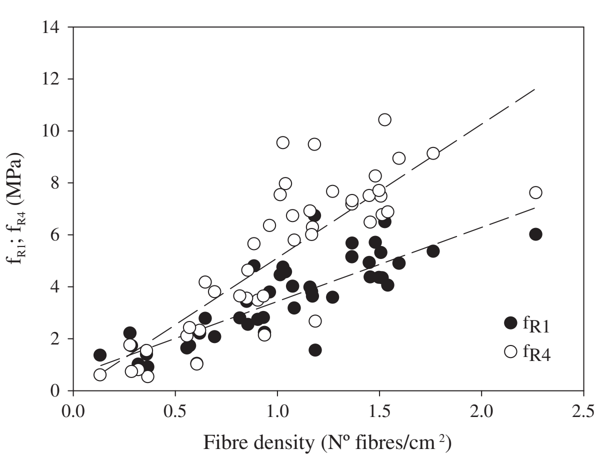

Fig. 3. Residual strength parameters f_{R1} and f_{R4} vs. density of fibres at the fracture surfaces. Slab prepared with steel FR-SCC.

flow, the residual capacity strongly decreases in beams perpendicularly oriented to the flow direction (IF).

Considering Sector II (centre of the slab: IIA, IIC and IID), the effect of flow is again appreciated. Beams IIA show a better post peak response than beams IID, which can also be attributed to a wall effect. In Sector III, although the residual capacity was again greater in parallel beams than in the perpendicular ones, at the end of the slab beams IIIE, IIIF and IIIG present similar responses with an increase in the variability of test results. Note that a more homogenous behaviour was observed in beams IIIA, IIIC and IIID. Finally comparing beams IIA vs. IIIA, IIC vs. IIIC, and IID vs. IIID an effect of flow rate can be verified. In Sector III the fibres are less oriented; which can be justified considering the decrease in concrete velocity and the influence of the end of the formwork.

From Table 1 it can be seen that f_L is similar in all sectors. This parameter is less affected by the fibre orientation and mainly depends on the matrix strength. On the contrary, the post peak parameters show strong differences between each sector and beam orientation; f_M has the highest mean value for the parallel beams of

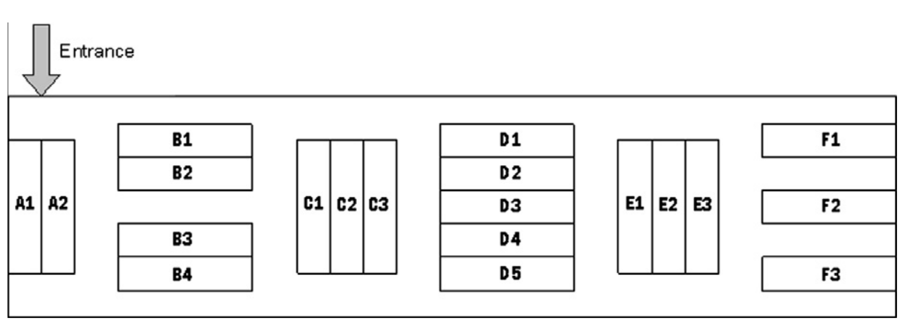

Fig. 4. Schema of the wall and the specimens obtained. FR-SCC incorporating steel fibres.

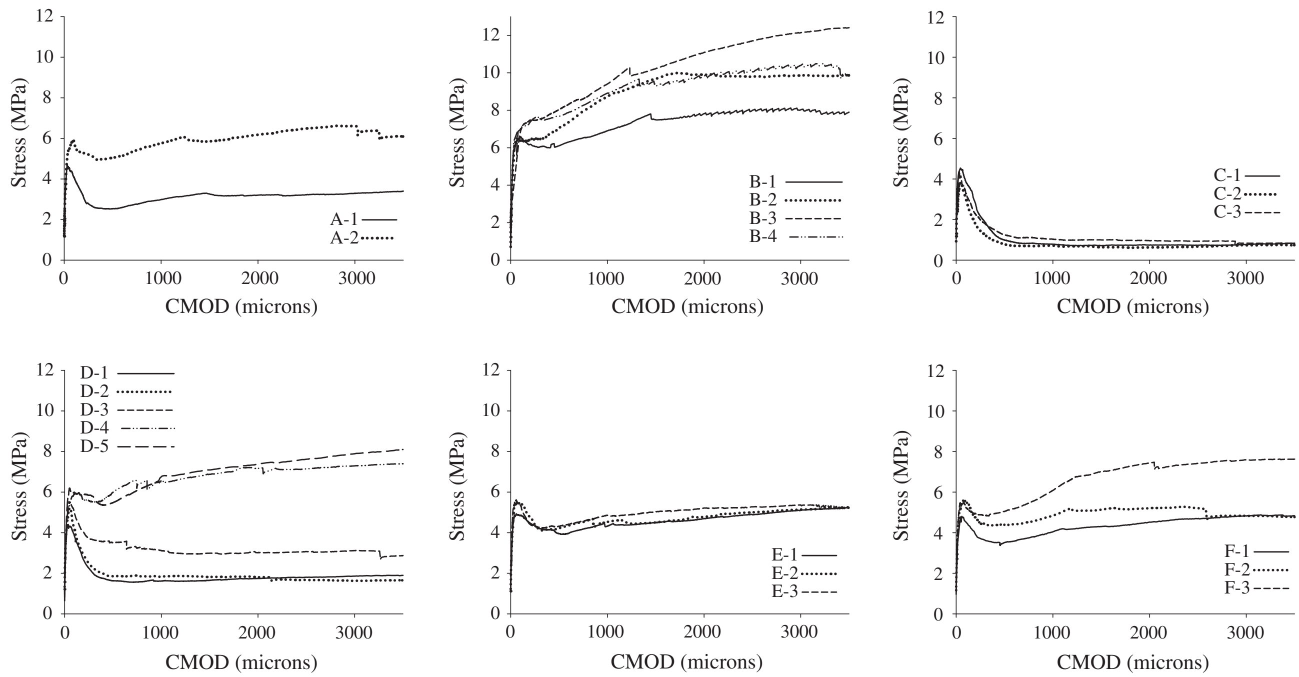

Fig. 5. Stress–CMOD curves of specimens cut from the wall. FR-SCC incorporating steel fibres.

Table 2
Wall prepared with steel FR-SCC. Summary of bending test results.

	f_L (MPa)	f_M (MPa)	f_{R1} (MPa)	f_{R2} (MPa)	f_{R3} (MPa)	f_{R4} (MPa)	Density (fibres/cm^2)
Horizontal beams – parallel to flow direction							
Mean	**5.5**	**8.0**	**5.3**	**6.4**	**6.8**	**6.9**	**1.71**
Maximum	6.3	12.5	8.0	10.2	11.7	12.4	2.44
Minimum	4.4	4.4	1.6	1.6	1.7	1.7	0.79
SD	0.7	2.7	2.4	3.4	3.7	3.9	0.63
Vertical beams							
Mean	**4.8**	**4.9**	**2.6**	**2.7**	**2.9**	**3.0**	**0.85**
Maximum	5.6	5.6	4.3	5.0	5.3	5.2	1.47
Minimum	3.9	3.9	0.8	0.6	0.7	0.7	0.14
SD	0.7	0.7	1.7	2.1	2.3	2.4	0.49

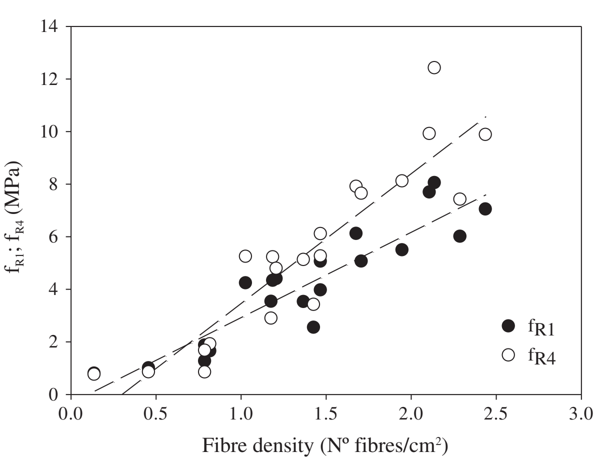

Fig. 6. Residual strength parameters f_{R1} and f_{R4} vs. density of fibres at the fracture surfaces. Wall prepared with steel FR-SCC.

Sector II followed by Sector I. The same happened with the residual strengths f_{R1}–f_{R4}. It must be remarked that there are significant changes in the residual parameters, which should be considered for structural design. As example in Sector II, f_{R1} and f_{R4} achieved 5.2 and 8.1 MPa, respectively, in parallels beams, and only 1.7 and 1.8 MPa when perpendicular beams are considered.

Fig. 3 shows the direct relationship between the residual strengths f_{R1} and f_{R4} and the density of fibres measured on the fracture surfaces. It must be noted that there is an important variation in the densities of fibres, although they correspond to specimens obtained from a same concrete.

Summarizing, these results show a clear effect of fibre orientation along Sector II where the differences between parallel and perpendicular beams are greater as well as the wall effect. In Sector III, the end of the formwork and the consequent reductions in the flow rate promote less orientation of the reinforcement leading to a more homogenous mechanical response.

2.3.2. Steel fibre reinforced concrete wall

Fig. 4 shows the test specimens (named as A–F) that were cut to evaluate the different zones of the wall. Beams A were cut from the place where the concrete was poured. Specimens C and D were obtained from the centre of the wall, normal (vertical) and parallel (horizontal) to the flow direction respectively. In the same way, near the end of the formwork, beams E and F were sawn.

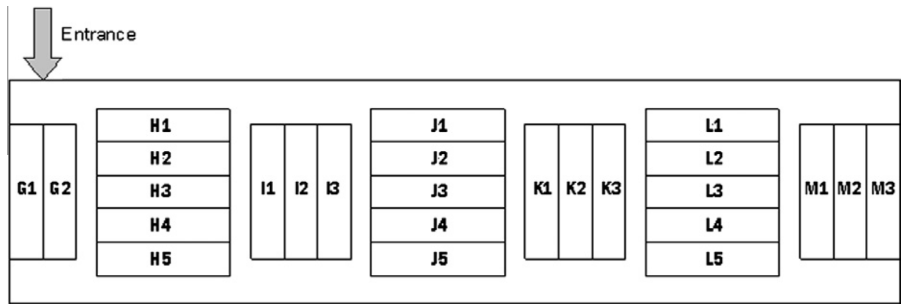

Fig. 7. Schema of the wall and the specimens obtained. FR-SCC incorporating synthetic fibres.

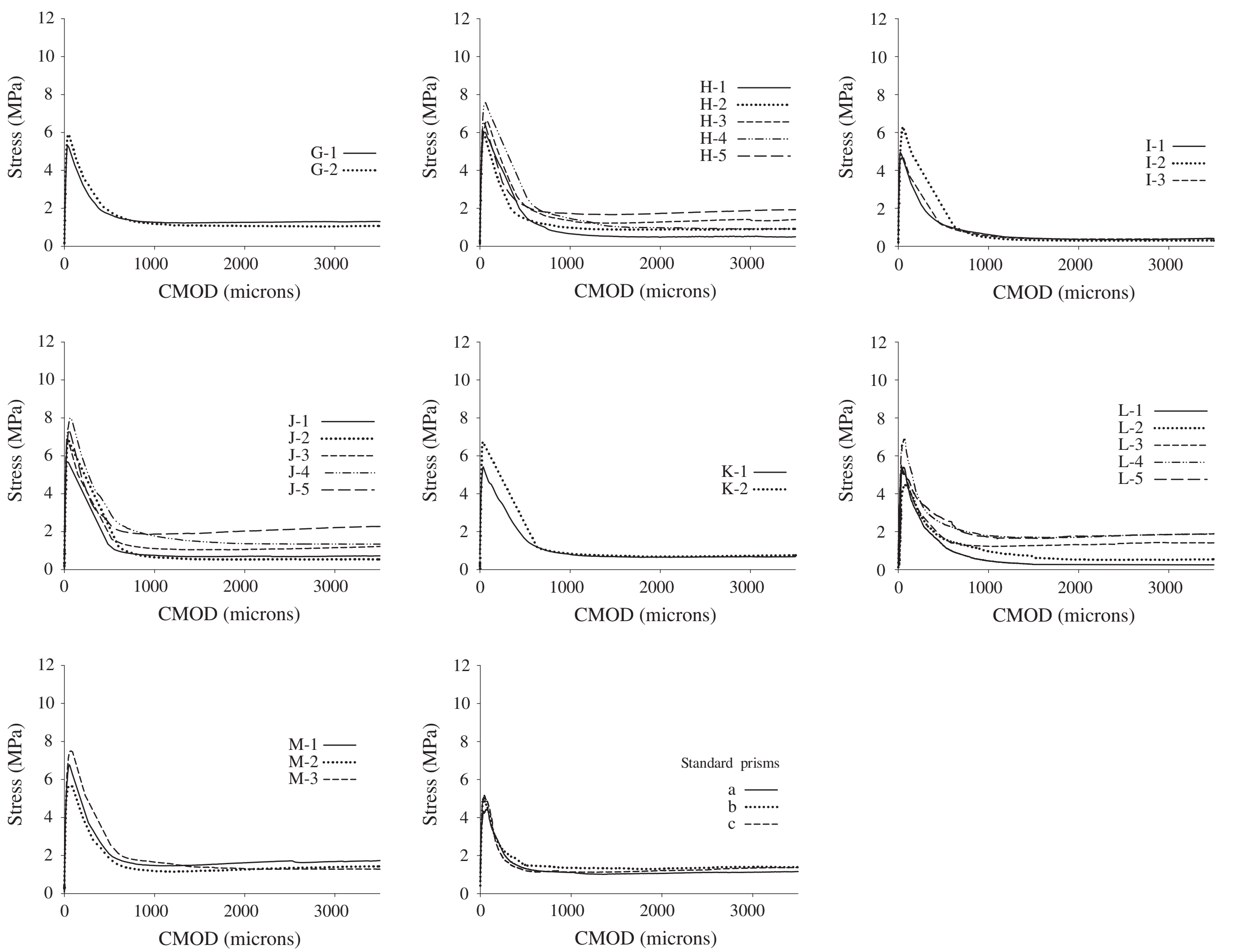

Fig. 8. Stress–CMOD curves of specimens from the wall. FR-SCC incorporating synthetic fibres.

The stress – CMOD curves corresponding to the different zones and directions of the wall are given in Fig. 5. The best post-cracking behaviour was found in B and some D beams (D4, D5), all of them parallel to the concrete flow. On the contrary, beams C show a post-cracking behaviour that is similar to plain concrete, with negligible capacity for controlling crack propagation. Finally, similar residual mechanical properties were found between the beams that were cut near to the end of the formwork (E and F), no matter the direction considered. It is interesting to note that beams D1 and D2 showed a clear softening type post-cracking behaviour; near to the top of the wall the concrete flow velocity was probably not enough to orient the fibres.

Table 2 compares the bending test results of beams cut parallel and normal to the concrete flow direction, groups A and F corresponding to the extremes of the wall were omitted. Fibre orientation is clearly reflected in the residual mechanical properties of the concrete leading to a significant improvement in the performance of parallel beams (horizontal). This effect is consistent with the density of fibres measured at the fracture surfaces.

The residual behaviour is clearly anisotropic and depends on the flowing direction of concrete favoured by the wall effect. In this sense, in parallel beams f_{R1} was twice the f_{R1} in normal beams, but considering f_{R3}, the differences were even higher (6.8 MPa vs. 2.9 MPa, respectively). It is interesting to note the strong

Table 3
Wall prepared with synthetic FR-SCC. Summary of bending test results obtained on cut beams and standard prisms.

	f_L (MPa)	f_M (MPa)	f_{R1} (MPa)	f_{R2} (MPa)	f_{R3} (MPa)	f_{R4} (MPa)	Density (fibres/cm^2)
Horizontal beams – parallel to flow direction							
Mean	**6.3**	**6.3**	**1.9**	**1.1**	**1.1**	**1.1**	**0.59**
Maximum	8.0	8.0	2.9	1.9	2.1	1.9	0.85
Minimum	4.5	4.5	1.2	0.3	0.3	0.3	0.25
SD	1.0	1.0	0.6	0.5	0.6	0.5	0.20
Vertical beams							
Mean	**5.3**	**5.3**	**1.2**	**0.5**	**0.5**	**0.5**	**0.34**
Maximum	6.7	6.7	1.7	0.7	0.7	0.7	0.48
Minimum	3.8	3.8	0.8	0.3	0.3	0.3	0.13
SD	1.1	1.1	0.3	0.2	0.2	0.2	0.14
Standard prisms EN 14651-2005							
Mean	**4.9**	**4.9**	**1.3**	**1.2**	**1.2**	**1.3**	**0.43**
Maximum	5.2	5.2	1.5	1.3	1.4	1.4	0.49
Minimum	4.3	4.5	1.2	1.0	1.1	1.2	0.39
SD	0.5	0.4	0.2	0.1	0.1	0.1	0.05

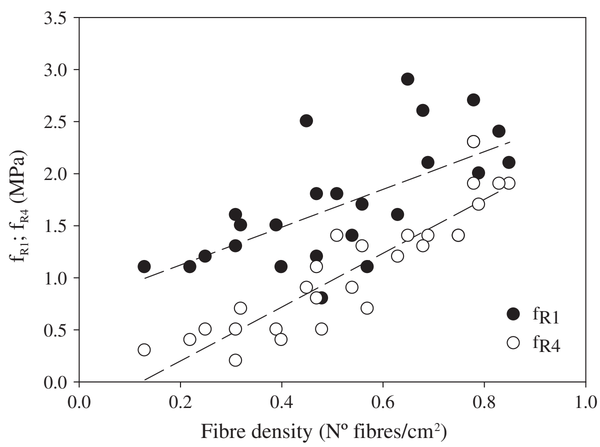

Fig. 9. Residual strength parameters f_{R1} and f_{R4} vs. density of fibres at the fracture surfaces. Wall prepared with synthetic FR-SCC.

differences between the maximum and the minimum f_{R4} (12.3 MPa vs. 0.7 MPa), indicating great differences in the crack control capacity for different directions. The same was found in the slab, where f_{R4} varies in a range from 10.4 MPa to 0.5 MPa.

Fig. 6 plots the results of the residual strengths vs. the density of fibres measured on the fracture surfaces. As expected, a good relationship was found between these parameters.

2.3.3. Synthetic fibre reinforced concrete wall

To compare the orientation tendencies of different fibres, the second thin wall was cast with a SCC reinforced with synthetic macrofibres. Test specimens (named as G–M) were cut from the wall as seen in Fig. 7. Beams G were cut from the place where concrete was poured; specimens I, J and K were cut from the centre in vertical, horizontal and vertical directions respectively; and beams L and M consider both directions near the end of the formwork.

Fig. 8 shows the stress – CMOD curves of the different groups. As expected, no hardening behaviour was found using this type of fibres. However, some differences can be seen in the post peak behaviour with little improvements in the performance of the horizontal beams. It is interesting to note that the post peak capacity of beams J and L increases as the depth increases. A similar situation but with greater differences was observed in the wall reinforced with steel fibres. These variations can be attributed to a higher flow rate at the bottom of the wall that enhances fibre orientation along the flow direction.

Table 3 presents bending test results corresponding to standard prisms (EN 14651) and those corresponding to perpendicular and parallel beams cut from the wall; beams G and M (extremes of the formwork) are excluded. As it was shown in the case of steel fibres, beams that were cut parallel to the concrete flow direction had a better post-cracking load capacity. On the contrary perpendicular beams showed the lowest residual parameters. EN 14651 beam tests results showed an intermediate post peak behaviour.

Fig. 9 represents the variation of the residual strength parameters with the density of fibres at the fracture surfaces.

2.3.4. Beams of 2.5 m length

Beams of $0.15 \times 0.15 \times 2.50$ m were cast with SCC reinforced with two types of steel fibres, 35 and 50 mm length. The former is the same fibre used in the slab and the wall. Four specimens 0.60 m long were cut from each beam to observe the effect of the flow distance. They were named as shown in Fig. 10 according to the length of the fibre used in each case.

Fig. 11 shows the stress – CMOD curves of standard and cut beams. Table 4 presents the obtained parameters. It can be seen that there were no significant differences between the cut beams, which also behaved like the standard specimens. The mean values are similar, both in the case of 35 mm and 50 mm length fibres. Only beam B50-1, which is affected by casting work, shows a light decrease in post-cracking parameters. It is important to mark that, contrary to what happened for thin elements, in these cases no significant fibre orientation along this structural element was observed.

3. Discussion

It is well known that fibres tend to adopt a disposition in planes (2D) both in conventional vibrated and in self-compacting FRC. However, in the last case, some factors can enhance one orientation into the planes.

The analysis of the diverse structural elements prepared with FR-SCC has shown a strong anisotropy in the distribution and orientation of the fibres that gives rise to important changes in the post peak parameters. This variation can achieve an order of magnitude, turning even from a hardening post-cracking behaviour to a response with poor residual capacity. These changes are mainly attributed to the rate of flow and the wall effect. Then, in thin FR-SCC elements there can be a strong variation in the residual properties of the material when different zones and directions are considered.

As a synthesis, Figs. 12–14 show the contours representing the variation of f_{R1}, f_{R4} and the density of fibres in the different zones of

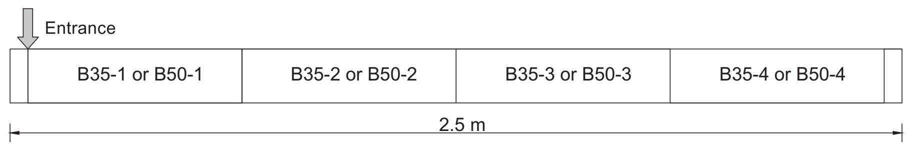

Fig. 10. Schema of the beam and the specimens obtained. FR-SCC incorporating steel fibres.

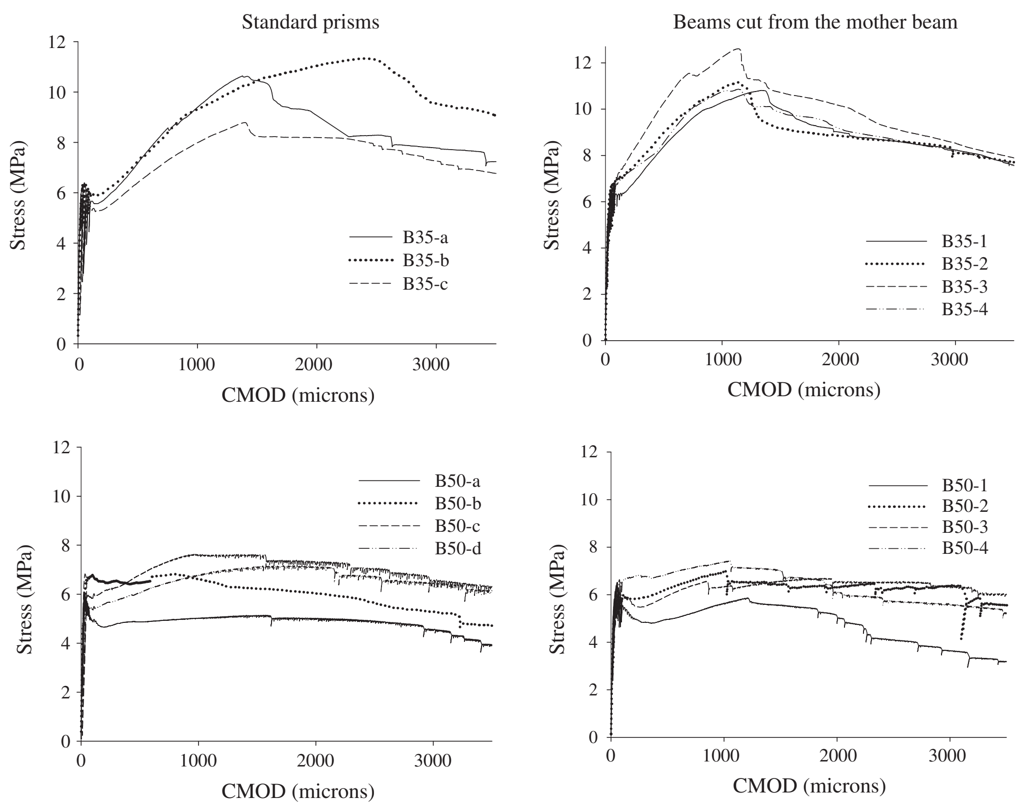

Fig. 11. Stress–CMOD curves obtained on standard prisms and beams cut from a 2.5 m length beam. FR-SCC incorporating steel fibres.

Table 4
Comparison of bending test results between specimens cut from 2.5 m length beams and standard prisms.

	f_L (MPa)	f_M (MPa)	f_{R1} (MPa)	f_{R2} (MPa)	f_{R3} (MPa)	f_{R4} (MPa)
B35: Cut beams						
B35–1	6.2	10.8	8.4	10.0	8.6	7.6
B35–2	6.7	11.2	9.0	9.2	8.6	7.7
B35–3	6.4	12.6	10.3	10.7	9.1	7.9
B35–4	6.2	10.9	8.6	9.9	8.7	7.6
Mean	**6.4**	**11.4**	**9.1**	**9.9**	**8.8**	**7.7**
B35 standard prisms EN 14651-2005						
Mean	**6.3**	**10.3**	**6.9**	**9.7**	**9.1**	**7.7**
SD	0.1	1.3	0.5	1.3	1.9	1.2
B50: Cut beams						
B50–1	6.4	6.4	5.0	5.6	4.1	3.2
B50–2	5.9	7.0	6.2	6.5	6.3	5.6
B50–3	5.8	6.7	6.0	6.6	6.5	6.0
B50–4	6.5	7.4	6.9	7.0	5.7	5.2
Mean	**6.1**	**6.9**	**6.0**	**6.4**	**5.7**	**5.0**
B50 standard prisms EN 14651-2005						
Mean	**6.3**	**6.9**	**6.0**	**6.5**	**6.1**	**5.3**
SD	0.5	0.6	0.8	1.1	1.0	1.2

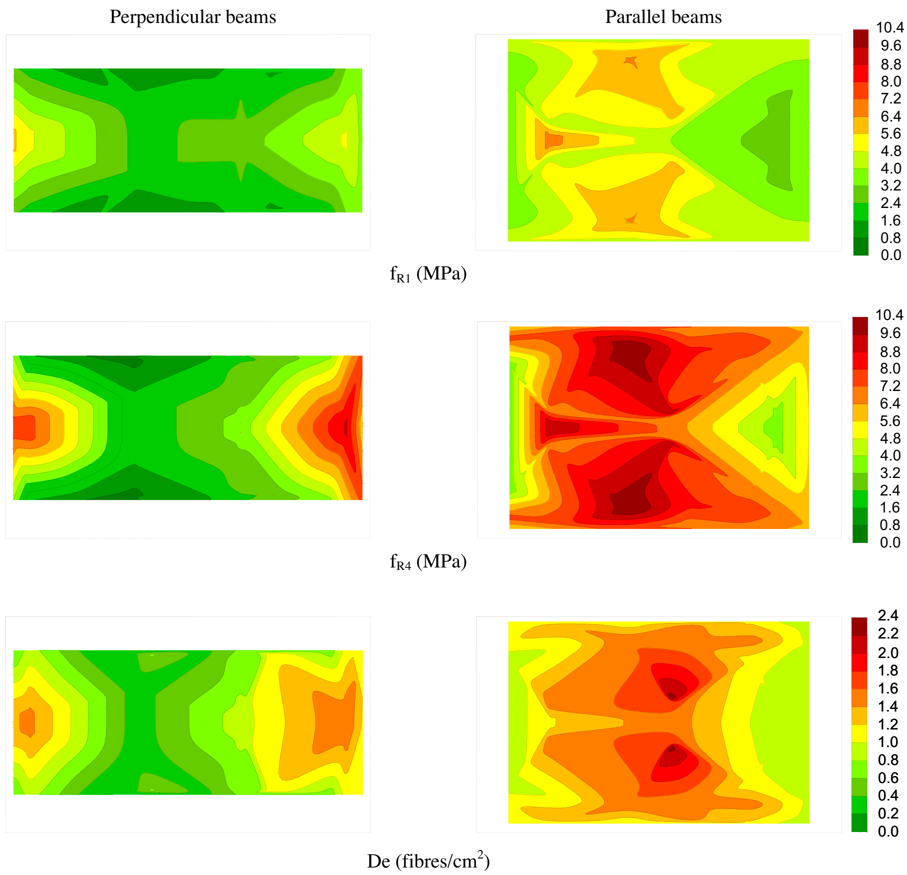

Fig. 12. Contours of the residual strength parameters and the density of fibres along the slab. FR-SCC incorporating steel fibres. Left: perpendicular beams, right: parallel beams.

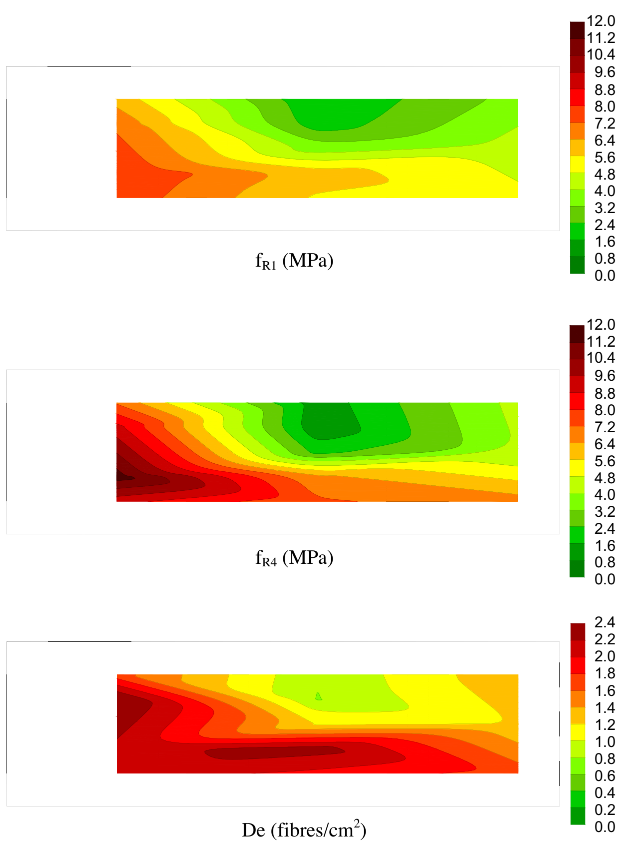

Fig. 13. Contours of the residual strength parameters and the density of fibres in the horizontal direction along the wall. FR-SCC incorporating steel fibres.

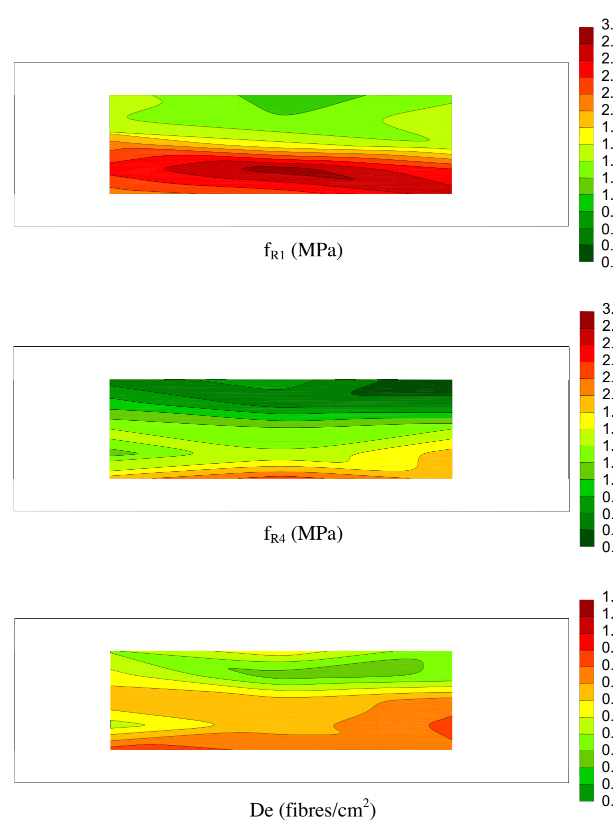

Fig. 14. Contours of the residual strength parameters and the density of fibres in the horizontal direction along the wall. FR-SCC incorporating synthetic fibres.

the structural elements studied. In the case of the slab (Fig. 12) both directions, parallel and normal to concrete flow, are included. All the contours correspond to the position of the fracture surfaces (see Figs. 1, 4 and 7).

Fig. 12 shows a great variation of the density of fibres and the residual properties along the slab as well as a strong relationship between them. The orientation of the fibres gives rise to very significant differences when parallel and perpendicular beams are considered. The perpendicular direction always shows lower density of fibres and residual strengths than the parallel direction.

Fig. 13 shows contours corresponding to the steel FR-SCC wall; the horizontal direction is represented. As was observed in the slab, the concrete flow and wall effects strongly influence the fibre orientation producing higher density and residual capacity near the bottom of the mould.

Fig. 14 shows contours representing the variation of f_{R1}, f_{R4} and the density of fibres in the horizontal direction of the wall cast with synthetic FR-SCC. As expected the differences are quite smaller than in the steel-fibres wall, but again, the concrete from the bottom has a better post-cracking behaviour.

These results show that the fibre orientation in FR-SCC structural elements varies with the flow rate and with the wall effect; the thickness of the elements or the proximity to the bottom of the moulds appears as important variables. Thus, there are great changes in the crack control capacity when considering different zones or orientations in thin elements (see Tables 1–3). The measured differences between the maximum and the minimum f_{R4} values from all beams range between 12.3 and 0.7 MPa in the steel FR-SCC wall, between 10.4 and 0.5 MPa in the steel FR-SCC slab, and between 2.3 and 0.2 MPa in the synthetic FR-SCC wall. In elements of higher thickness (2.50 m length and 150 mm side beams) the orientation produced by concrete flow was not important. The variability of the residual properties along the beam length was similar to that usually found between standard specimens.

Finally it is important to remark that the variations between different zones and directions of a thin structural element can be even higher than those that appear between concretes made with different types and contents of fibres.

4. Conclusions

This paper presented the response of diverse structural elements prepared with FR-SCC. It was demonstrated that:

- The flow rate and the wall effect produce a marked anisotropy and heterogeneity in fibre distribution and orientation.
- In thin elements the residual mechanical properties of FR-SCC can be quite different when diverse zones and/or directions of the structural elements are considered.
- The variation in post-cracking response within a same structural element can even include a hardening type behaviour or a substantial fall of the residual load capacity.
- Although the distribution and orientation of the fibres are not completely independent of the fibre type, the geometry of the elements appears as the main factor to be considered.

This paper clearly shows that there can be significant differences in toughness and residual capacity when diverse zones and directions of FR-SCC structural thin elements are analyzed. The orientation of fibres is affected by the flow rate and wall effects, and this must be considered for structural design as well as for modelling the performance of the FR-SCC.

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