REVISTA DE DESIGN, INOVAÇÃO E GESTÃO ESTRATÉGICA REDIGE REVIEW ON DESIGN, INNOVATION AND STRATEGIC MANAGEMENT
ISSN 2179-1619

Oriented fibrous structures for concrete reinforcement

Mario de Araujo
PhD, Senior Professor, School of Engineering, University of Minho, Portugal

Raul Fangueiro
PhD, Auxiliary Professor, Department of Textile Engineering, University of Minho, Portugal

Cristiana G. Pereira
PhD student, Department of Civil Engineering, University of Minho, Portugal

Paula P. Marques
MSc student, Department of Textile Engineering, University of Minho, Portugal

---

Abstract

This paper reports on the work that is being undertaken at the University of Minho concerning the development of directionally oriented fibrous structures (DOFS) to be used as a concrete reinforcement material. Several glass fibre *wovenlike* DOFS were produced varying two parameters: roving linear density (tex) and reinforcement structural density (rovings/cm). Self-compacting concrete slabs were reinforced by DOFS structures and their bending behaviour was evaluated. The results were compared with those of steel reinforced slabs and plain (non reinforced) concrete slabs. They show that DOFS improve the mechanical behaviour of self-compacting concrete, however, their mechanical behaviour is different from steel.
Keywords: Textile reinforced concrete. Glass fibre. W*ovenlike* grid. Mechanical properties.

1 Introduction

The development and replacement of conventional construction materials, by better performing ones, is receiving a great deal of attention by the textile and civil engineering scientific communities. The use of fibrous materials as reinforcement for cementitious matrices is one of its many applications that have resulted in new product developments.

Due to its inherent low tensile strength, concrete requires reinforcement in applications where significant tensile stresses are applied, in order to maximize its load-bearing capability and improve its toughness. Steel reinforced concrete is widely used in the construction industry, being one of the most important building materials. However, corrosion of steel is one of its most serious problems which leads to a limited service life (PİLLAİ, S. U. et al, 2003).

Textile Reinforced Concrete (TRC) is a new approach to concrete reinforcement which is being developed in the last years in order to solve steel corrosion problems and improve the serviceability and performance durability of steel reinforced concrete structures (BRAMESHUBER, W., 2006). Easy handling, transportation and placing in site, corrosion resistance and the ability of fibre orientation in the load application directions are the main reasons for its use. Besides, the use of fibrous materials allows the production of thin and lightweight elements that are corrosion-resistant, durable, of low cost and with increased load-bearing capabilities whilest significantly improving its ductility. (GRİES, T. et al, 2004). Thus, fibrous materials have the ability to provide new architectural possibilities for the design of concrete structures.

The current research work consists in the development and application of directionally oriented fibrous structures (DOFS) as a concrete reinforcement material, in order to overcome the main disadvantages of steel corrosion. E-glass fibre DOFS reinforced concrete elements were produced and the influence of the rovings linear density and the *wovenlike* grid structural density on the reinforced concrete mechanical behaviour were studied.

2 Experimental work

A variety of light E-glass fibre DOFS reinforced concrete slab samples were prepared, and the influence of the geometry and density of the reinforcing materials, i.e. rovings linear density and *wovenlike* grid structural density, on the mechanical behaviour of the reinforced concrete were analysed.

2.1 Materials

The criteria used to choose E-glass fibre for producing the DOFS were adequate tensile properties, low thermal conductivity and good relation quality/price. A self-compacting concrete (SCC) was produced in order to evaluate the mechanical performance of the glass fibre DOFS reinforced concrete. SCC was the selected concrete type due to its specific features namely high tensile properties and not requiring vibration for placing and compaction. The composition of the SCC produced is given in Table 1. A cement type I 42.5 R was used and a calcareous filler was added as well as a 3rd generation super plasticizer.

Table 1: SCC composition

Components	***Quantity***
CEM I 42.5 R	289.33 kg/m^3
Calcareous Filler Micro 100 A	376 kg/m^3
Water	161.27 l/m^3
Superplasticizer SikaViscocrete 3006	5.07 l/m^3
Sand	738.2 kg/m^3
Granite aggregates 4/10*	756 kg/m^3

Note: at least 95% of the aggregate particles has dimension higher than 4mm; at least 90% of the aggregate particles has dimension lower than 10mm

All DOFS were developed based on the basic plain weave structure. The DOFS reinforcement consisted of a biaxial (2D) *wovenlike* structure with 0/90^0 E-glass fibre orientation (longitudinal and transversal direction). The DOFS were characterized by an open structure with different number of rovings in each orthogonal direction, in order to study the load bearing capacity behaviour in each particular direction. The linear density of each single roving used in the longitudinal direction was 2130 *tex* and of those used in the transversal direction was 2140 *tex*.

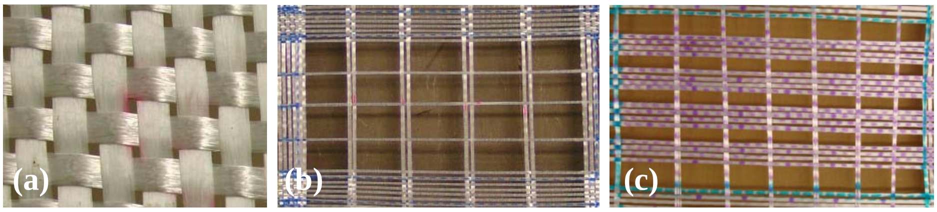


Figure 1 - (a) basic plain weave (b and c) examples of DOFS structures

Ten different DOFS samples were developed, varying the rovings linear density and the *wovenlike* grids structural density. These samples were organised in five groups in order to study the influence of some geometrical and dimensional parameters of the DOFS on the mechanical properties of the DOFS reinforced concrete slabs:

- Group 1 (DOFS 1, 2, 7): evaluation of the influence of an increase of structural density in the longitudinal direction, keeping the parameters of the transversal direction constant (linear density and structural density constant);
- Group 2 (DOFS 1, 3, 4): evaluation of the influence of an increase in linear density in the longitudinal direction, keeping the transversal direction constant (linear density and structural density constant);
- Group 3 (DOFS 2, 3, 10): evaluation of the influence of an increase in linear density and structural density in the longitudinal direction, keeping the transversal direction constant (linear density and structural density constant);
- Group 4 (DOFS 3, 5. 8) and Group 5 (DOFS 2, 6, 9): evaluation of the influence of an increase of structural density in the transversal direction (linear density constant), keeping the parameters of the longitudinal direction constant (linear density and structural density constant);

Table 2 shows the geometrical and dimensional characteristics of the DOFS structures. Figure 2 shows schematic diagrams of the ten DOFS structures developed.

Table 2: DOFS geometrical characterization

Samples	***Longitudinal reinforcement***		***Transversal reinforcement***	
ID	Roving linear density (tex)	Structural density (rovings/15cm*)	Roving linear density (tex)	Structural density (rovings/30cm*)
$DOFS_1$	2130	4	2140	6
$DOFS_2$	2130	8	2140	6
$DOFS_3$	4260	4	2140	6
$DOFS_4$	8520	4	2140	6
$DOFS_5$	4260	4	2140	3
$DOFS_6$	2130	8	2140	3
$DOFS_7$	2130	16	2140	6
$DOFS_8$	4260	4	2140	12
$DOFS_9$	2130	8	2140	12
$DOFS_{10}$	8520	2	2140	6

Note: Corresponds to the slab dimensions 15x30 cm^2

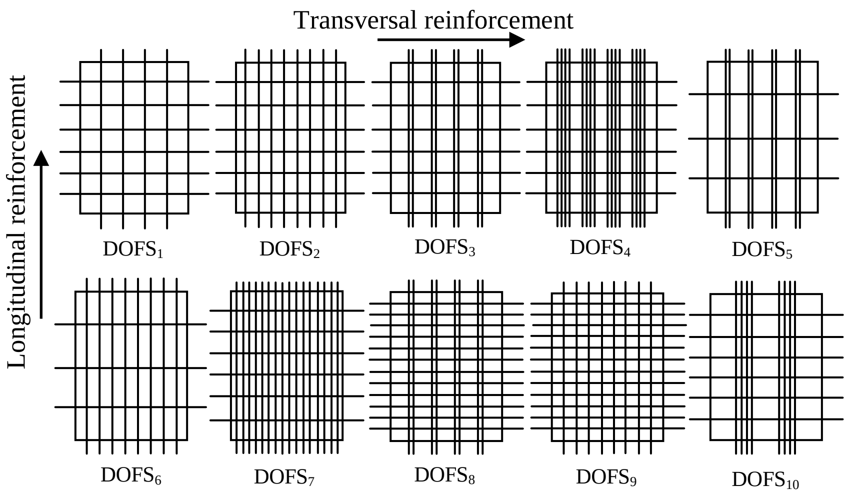
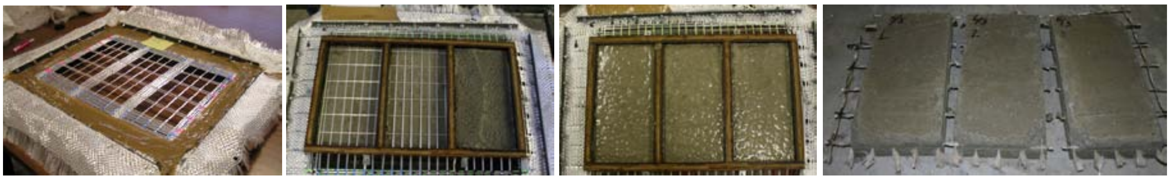


Figure 2 - DOFS structures schematic representation

The DOFS were produced using a pre-stressing frame, in order to achieve a completely stretched fibrous structure, in both the transversal and longitudinal direction (Fig. 3a). A SCC layer of 1cm height was laid inside the mould. The stretched DOFS were then placed above the layer of SCC (Fig. 3b). Finally, a second layer of SCC 3cm thick was laid on top of the DOFS (Fig. 3c). The DOFS reinforced concrete samples (Fig. 3d) were demoulded after 24 hours and placed in a controlled environment during 28 days before testing. A total of 30 samples of DOFS reinforced concrete were produced with the 10 different

DOFS structures. In addition, one set of 3 samples of plain (non-reinforced) concrete slabs and another set of 3 samples of steel reinforced concrete slabs were also produced for comparative purposes with the DOFS reinforced concrete slabs mechanical behaviour. In the steel reinforced concrete slabs there was no interlacing of the longitudinal and transversal reinforcements. The samples dimensions were 15 x 30 x 4 cm^3.



(a) (b) (c) (d)

Figure 3 - Production process of the DOFS concrete reinforced slabs

2.2 Test Method

Three-point bending tests were carried out to evaluate the mechanical performance of the DOFS concrete reinforced slabs, the plain concrete slabs and the steel reinforced concrete slabs according to EN 1339:2003, annex F European Standard (Standard EN 1339, 2003). The tests were conducted so that the face of the sample at 1cm of the reinforcement material was under tension. The slabs dimensions were 30cm length, 15cm width and 4cm thickness. The distance used between the load bearing support and the edge of the flag was 25cm. The bending strength was determined, according to the following equation (1):

$$T = \frac{3 \times P \times L}{2 \times b \times t^2} \tag{1}$$

Where, ***T*** is the bending strength [MPa], ***P*** is the breaking load, [N], ***L*** is the distance apart of the supports [mm], ***b*** is the width of the slab [mm], and ***t*** is the thickness of the slab [mm].

3 Results and Discussion

The DOFS reinforced self-compacting concrete slabs are identified using the following abbreviations. *SCC DOFS*, meaning self-compacting concrete slab reinforced with a directionally oriented fibrous structure, followed by a number corresponding to the DOFS used. Regarding to the concrete slab without any type of reinforcement the abbreviation used was SCC_{plain} meaning plain self-compacting concrete slab, while for the steel reinforced slab the abbreviation used was SCC_{steel}. The average bending test results for DOFS reinforced concrete slabs, plain self-compacting concrete slabs and steel reinforced self-compacting concrete slabs are summarized in Table 3.

Table 3: Bending results grouped according to the established relations

Group ID	*Samples ID*	*Reinforcement (% by volume)*	*Bending strength (MPa)*	*Strain*
1	SCC $DOFS_1$ SCC $DOFS_2$ SCC $DOFS_7$	0.08 0.13 0.22	7.41 7.37 7.64	0.0021 0.0020 0.0016
2	SCC $DOFS_1$ SCC $DOFS_3$ SCC $DOFS_4$	0.08 0.13 0.22	7.41 7.20 8.34	0.0021 0.0017 0.0020
3	SCC $DOFS_2$ SCC $DOFS_3$ SCC $DOFS_{10}$	0.13 0.13 0.13	7.37 7.20 8.03	0.0020 0.0017 0.0035
4	SCC $DOFS_5$ SCC $DOFS_3$ SCC $DOFS_8$	0.11 0.13 0.16	7.85 7.20 5.99	0.0025 0.0017 0.0022
5	SCC $DOFS_6$ SCC $DOFS_2$ SCC $DOFS_9$	0.11 0.13 0.16	7.89 7.37 6.62	0.0019 0.0020 0.0018
----------	SCC_{plain} SCC_{steel}	------ 0.62	6.03 13.89	0.0023 0.0110

Analysing Table 2, the SCC_{plain} slab and the SCC $DOFS_8$ present the lowest bending strength. It would be expected that the plain concrete slab presented the lowest value of bending strength due to the absence of any reinforcement. However, the SCC $DOFS_8$ presents the lowest value of all and that may be explained by two reasons: excessive crimp in the longitudinal direction leading to high crimp interchange at the initial stage of extension and also by the possible use a different concrete quality. The slab reinforced with steel (SCC_{steel}), as expected, presents the highest value of bending strength. This is because the slab presents about 4 times more reinforcement by volume than the other slabs, the higher modulus of steel and also the absence of any crimp. Regarding to the directionally orientated fibrous structures, the one which presents the best bending performance is the slab reinforced with the $DOFS_4$ and this is possibly because there is a high fibre percentage in the longitudinal direction where the loads are applied. With the exception of sample SCC $DOFS_8$, all other the samples reinforced with the fibrous structures present a higher bending performance when compared to the unreinforced sample (SCC_{plain}) and so the DOFS reinforced concrete slabs improve the mechanical behaviour of concrete elements.

Figure 4 shows the bending behaviour for the Group 1 structures (DOFS 1, 2, 7) so that the influence of varying the structural density in the longitudinal direction while keeping constant the transversal direction parameters may be studied. Slab SCC $DOFS_1$ presents the worst mechanical behaviour, due to the lower structural density of the rovings and the smaller amount of fibres in the slab (0.08%). Slab SCC $DOFS_7$ shows the best mechanical performance, as it has the highest structural density in the longitudinal direction and the highest amount of fibres in the slab (0.22%), and this leads to a better performance, once the number of micro cracks intercepted by the fibres is higher. As expected, the higher the amount of fibres in the load application direction (longitudinal direction) the better is the slab performance.

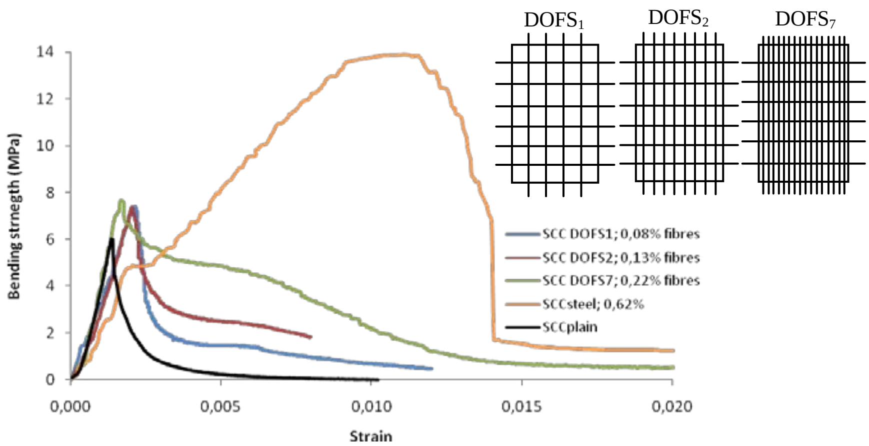


Figure 4 - Group 1 bending strength *vs* strain curve

Figure 5 shows the bending behaviour for the Group 2 structures (DOFS 1, 3, 4) so that the influence of varying the linear density in the longitudinal direction while keeping constant the transversal direction parameters may be studied. Slab SCC $DOFS_1$ shows the worst mechanical behaviour once it has the lowest amount of load bearing fibres (8520 Tex) in the longitudinal direction. Slab SCC $DOFS_4$ is the sample presenting the best mechanical behaviour, and this is because it has a higher amount of load bearing fibres (34080 Tex) in the longitudinal direction. Accordingly, it seems that a linear density increase works as a barrier to cracking allowing higher loads to be transferred and partly absorbed by the fibres thus creating a better distributed cracking of the slab. With an increase of the number of fibres, there seems to be less crack opening and the total area of the cracks may be reduced. It seems that increasing the linear density in the longitudinal direction improves the bending performance of the slab.

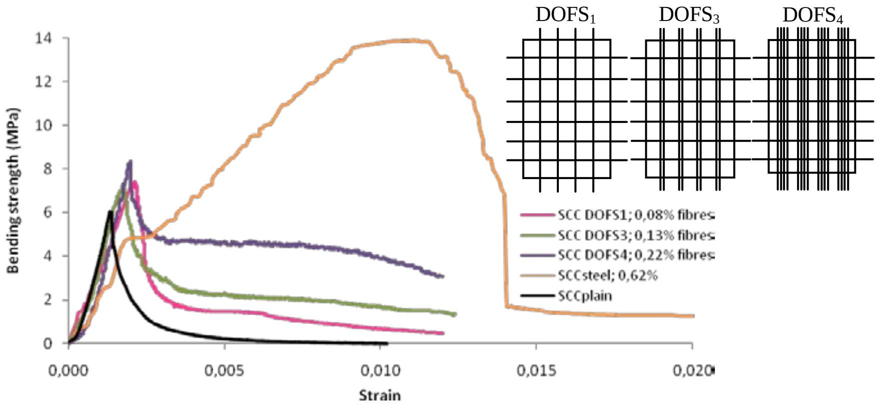


Figure 5 - Group 2 bending strength *vs* strain curve

Figure 6 shows the bending behaviour for the Group 3 structures (DOFS 2, 3, 10) so that the influence of varying the longitudinal rovings linear density and structural density while keeping the transversal parameters constant may be studied. Analysing Figure 6 the following conclusions may be established: SCC $DOFS_2$ and SCC $DOFS_3$ slabs present similar mechanical behaviour. The SCC $DOFS_{10}$ slab presents a different behaviour than the other two once it shows higher values of bending strength and higher values of bending strain.

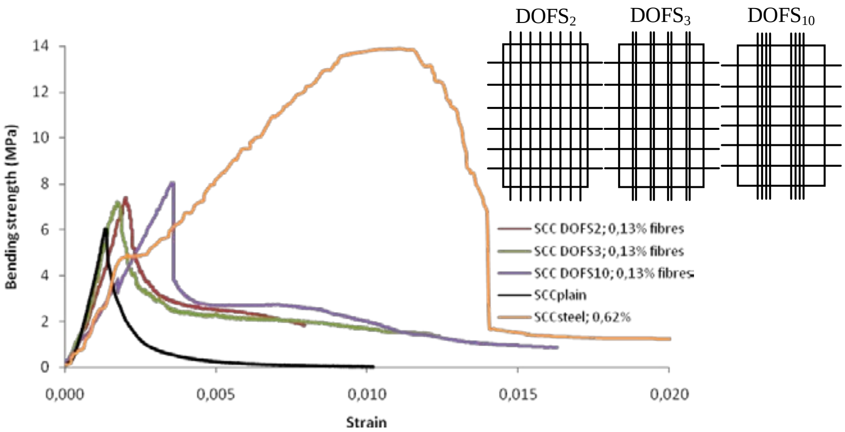


Figure 6 - Group 3 bending strength *vs* strain curve

Figure 7 shows the bending behaviour for the Group 4 structures (DOFS 3, 5. 8) so that the influence of varying the transversal structural density while keeping the longitudinal structural density constant (rovings linear density constant in both directions) may be studied. Analysing the results it is possible to infer that sample SCC $DOFS_5$ which is reinforced with a lower transversal structural density and has the least % of reinforcement fibre, shows the best mechanical behaviour and this is because there is less crimp interchange at the beginning of the extension. The SCC $DOFS_8$ slab which is reinforced with a higher transversal structural density and % of reinforcement fibres shows the worst mechanical behaviour and this is because there is high crimp interchange at the beginning of the extension. The increase of structural density in the transversal direction does influence on bending mechanical performance in the longitudinal direction where the loads are applied.

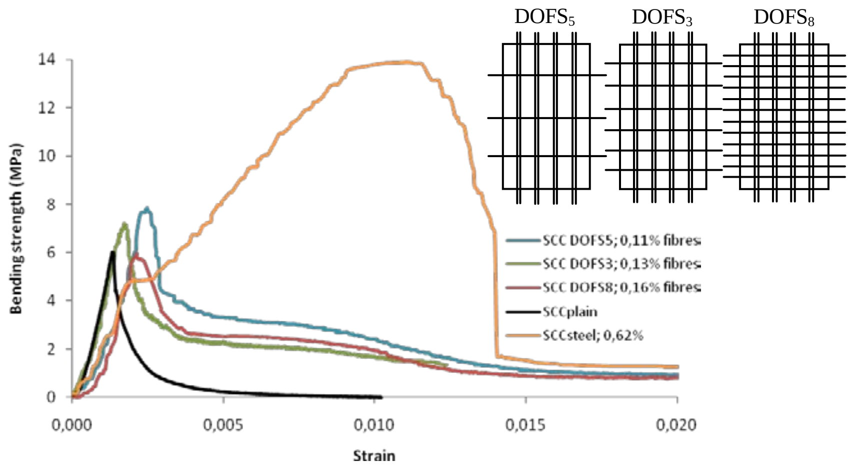


Figure 7 - Group 4 bending strength *vs* strain curve

Figure 8 shows the bending behaviour for the Group 5 structures (DOFS 2, 6, 9) so that the influence of varying the transversal structural density while keeping the longitudinal structural density constant (rovings linear density constant in both directions) may be studied. This is a similar situation as in Group 4 and is useful to confirm or deny the results. Analysing the results it is possible to infer that sample SCC $DOFS_6$ which is reinforced with a lower transversal structural density and has the least % of reinforcement fibre, shows the best mechanical behaviour and this is because there is less crimp interchange at the beginning of the extension. The SCC $DOFS_9$ slab which is reinforced with a higher transversal structural density and % of reinforcement fibres shows the worst mechanical behaviour and this is because there is high crimp interchange at the beginning of the extension. The increase of structural density in transversal direction does influence the bending mechanical performance in the longitudinal direction and this confirms the results already found with Group 4.

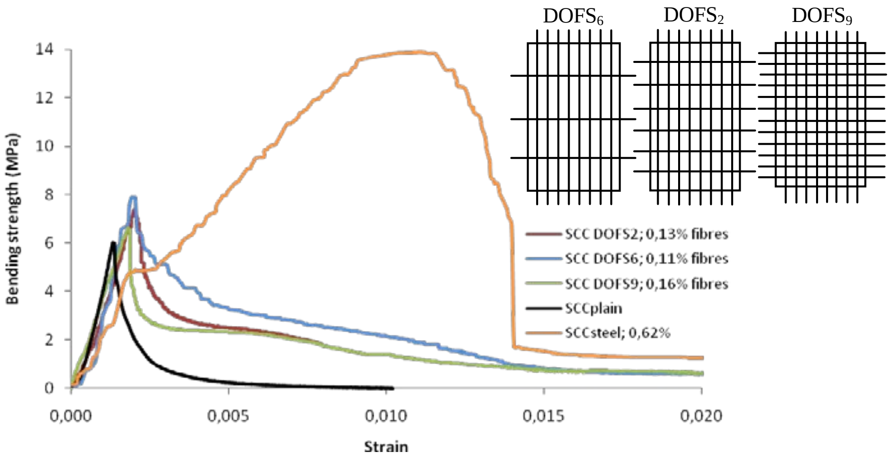


Figure 8 - Group 5 bending strength *vs* strain curve

4 Conclusions

Analysing the results obtained the conclusions are as follows:

- The unreinforced SCC_{plain} slab did not perform well in bending due to the absence of any reinforcement while the steel reinforced concrete slab (SCC_{steel}) presented the best bending behaviour due to the high % of reinforcement present, the higher modulus of steel and the absence of crimp;
- With the exception of sample SCC $DOFS_8$, all other DOFS improved the concrete elements bending behaviour;
- SCC $DOFS_1$ which had the lowest linear density (8520 tex) in the loading direction, did not perform so badly overall, showing that crimp interchange has a worse effect than that due to the amount of fibre in the loading direction;
- SCC $DOFS_4$ presents the best mechanical behaviour with the highest percentage of fibres (0.22%) and the highest linear density (34080 tex) in the load bearing direction;
- Both roving linear density and structural density have shown to have a significant influence on the reinforced concrete element mechanical behaviour;
- The higher the linear density of the roving, the structural density of the grid, the amount of fibres in the loading direction (longitudinal) and the lower the structural density in the transverse direction, the better is the mechanical performance of the reinforced concrete.

5 References

BRAMESHUBER, W. **State-of-art report of rilem technical committee 201 – TRC textile reinforced concrete**. Report 36. 3rd Trimester, 2006.

GRIES, T; ROYE, A. et al. New development on manufacturing fibres and textile structures for technical textiles. In: INTERNATIONAL TEXTILE CONGRESS, Terrassa, 18-20 October, 2004. **Book of proceedings.**

PILLAI, S. U.; DEVADAS, M. **Reinforced concrete design**. Tata McGraw-Hill, 3. ed. 2003.

STANDARD EN 1339:2003: **Concrete paving flags – Requirements and test methods: Annex F - Measure of bending strength and breaking load**.

Biographical Notes

Mario de Araujo has a PhD in Textile Engineering and, he is Senior Professor at University of Minho. He is a specialist in Textile Product Design and Development.
Email address: mario.araujo@det.uminho.pt

Raul Fangueiro has a PhD in Textile Engineering, and he is Auxiliary Professor at University of Minho. He is a specialist in Technical Textiles.
Email address: rfang@det.uminho.pt

Cristiana G. Pereira is a MSc in Civil Engineering, and she is a PhD student at University of Minho and a Lecturer in Civil Engineering at Setubal Polytechnic (Portugal).
Email address: cristiana.pereira@civil.uminho.pt

Paula P. Marques is a MSc in Textile Engineering and, she is currently working in industry.