Effect of manufacturing methods on tensile properties of fibre concrete

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ABSTRACT: This Paper presents the first results of the experiments of fibre reinforced concrete tested using a newly developed uniaxial tensile test. The aim was to develop a tensile test set-up in which the specimen supports have no restraind freedom of movements. This goal has been achieved by means of an arrangement based on 'pendulum-bars'. Different filling/casting methods were used for optimizing the fibre distribution and orientation aimed at an increase of the tensile strength will increase. Results of a test series, where the filling method, the type and the amount of fibres are varied is presented in this paper.

1 INTRODUCTION

Compaction may have a significant influence on the properties of fibre reinforced concrete. In particular fibre orientation and fibre distribution may be affected, especially when vibration needles are inserted in the fresh concrete. With the development of self compacting concrete, the use of vibrational energy for compaction has become obsolete, and with current generation of super-plasticizers it is possible to develop self-compacting fibre concrete as well (Grünewald (2004), Markovic (2006), Stähli (2004), Stähli (2007), Rossi (1996)). Increasing the amount of fibres may have a positive effect on the mechanical properties, but because fibres are not all necessarily aligned in the direction of stress, the effectivity is debatable. Better would be to align fibres in the direction of stress, which might lead to improved performance of fibre reinforced concrete (FRC) and hybrid fibre concrete (HFC) in a structure, probably against lower cost. Not only strength should be considered, but also ductility.

Aligning fibres has been tried in the past under a variety of circumstances. Recently a method based on magnetic fields was proposed by Linsel (2005). For SIFCON, fibre alignment can be achieved by sprinkling fibres in a narrow space, or in very thin elements (Van Mier (1992), van Mier (1996)). Moreover, during extrusion of FRC, fibres align in the longitudinal direction as well (see for example Shao (1997), leading to quite some anisotropy with, probably the related differences of properties in the various directions.

As mentioned, the development of self-compacting concrete leads to easier placement of the fresh material, and the fibre distribution and orientation is not affected since compaction becomes obsolete. An interesting idea is to investigate to what extent the filling method of the fresh material can be used to affect the fibre distribution and orientation, and to see if a possible influence on the mechanical properties emerges. In this paper a test series is reported that confirms that the filling method has an influence on the mechanical properties of fibre reinforced materials. These and earlier experiments also show that material properties for fibre reinforced materials are dependant on the geometry of the tested specimen. Therefore, parameters, such as the tensile strength, are not constant for the whole specimen. They change with the flow and the geometry of concrete in the specimen and that means that structures can not be conventionally designed. Moreover, the whole filling process has to be taken into account to design structures. This is also a chance for optimizing a structure by controlling the flow of the material so that fibres are orientated most favourably and perhaps fewer fibres need to be used.

This paper also introduces a newly developed tensile test using pendulum bars. This test set-up was specially designed for materials like hybrid fibre concrete with a maximum uniaxial tensile strength of 20 MPa and a maximum fibre length of 30 mm.

2 FILLING METHODS AND MATERIAL

In order to optimize the filling process and the resulting fibre orientation and distribution three different filling methods were performed. The ‘conventional’ method (C), where the concrete was filled from the top and the material did not flow, but falls in the mould (Fig 1); the ‘filling’ method (F), where the concrete was filled in the mould in such a way that the material flowed a little (Fig. 2) and the ‘climbing’ method (CL), where the material was filled/pumped from the bottom to the top of the mould (Fig 3).

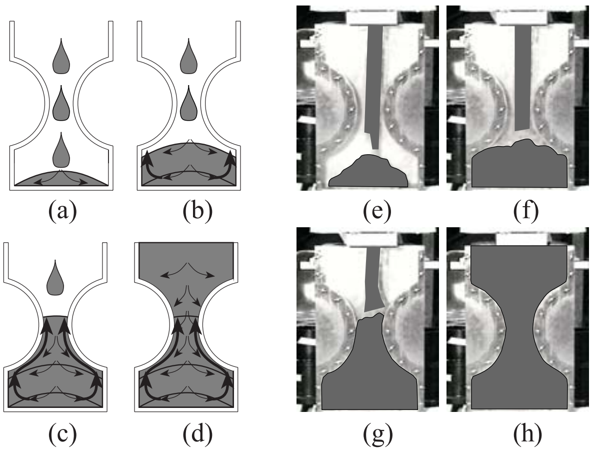


Figure1. Sketch (a to d) and images (e to f) of the filling sequence of a tensile specimen with the ‘conventional’ method. The arrows show the direction of the flow of the material during the filling process.

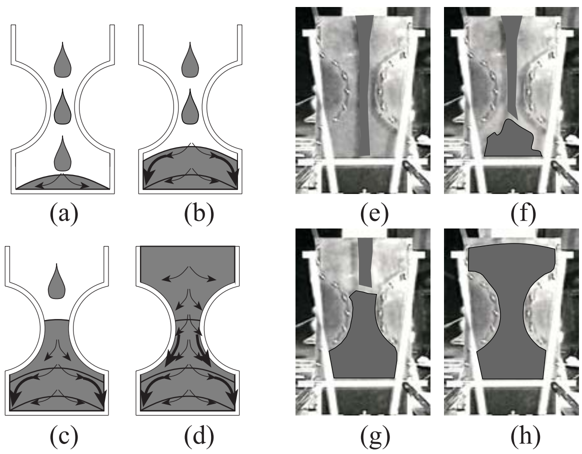


Figure 2. Sketch (a to d) and images (e to f) of the filling sequence of a tensile specimen with the ‘filling’ method. The arrows show the direction of the flow of the material during the filling process.

Due to the available equipment in the laboratory (no concrete pump was available) the ‘climbing’ method was performed in such a way, that the material first was filled in the ‘filling’ method specimen and there, the material flowed trough a connecting part and climbed up into the ‘climbing’ method specimen (Fig. 4). The difference between the conventional and the filling method is in the flow of the material. Figure 1b shows that as soon as the material starts to fill the mould, the material starts to flow upwards and concrete swirls develop. This also happens when the mould is almost filled (Fig. 1c). Figure 2b and c show that the material starts to flow downwards the more the mould is filled. No swirls develop and the fibres can properly align in the direction of the material flow.

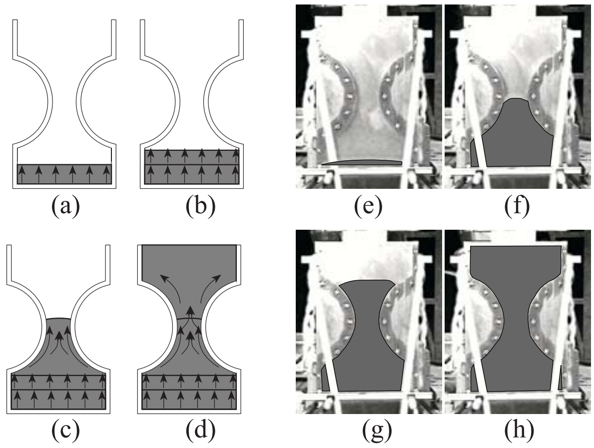


Figure 3. Sketch (a to d) and images (e to f) of the filling sequence of a tensile specimen with the ‘climbing’ method. The arrows show the direction of the flow of the material during the filling process.

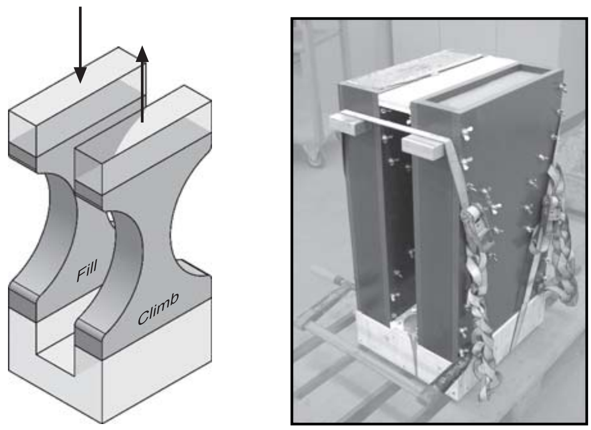


Figure 4. Sketch and image of the ‘U-Shaped’ mould for the tensile test specimens

To ensure that the fibres did not segregate and the material was capable to self-level the diameter of the small slump flow of the fresh material had to be in-between 20 and 26 cm. The concrete matrices only differed in the amount of super-plasticizer because of the aim to have equal rheological properties for all the mixtures. In most of the mixtures additional super-plasticizer was added to increase the flow ability of the material. Three mixtures with only one type of steel fibre and two hybrid fibre concretes with three different types of steel fibres were investigated. An overview of all the mixtures and their respective rheological properties is given in Table 1.

The matrix was composed as follows: 1000 kg/m^3 CEM I 52.5R, 200 kg/m^3 fly-ash, 100 kg/m^3 Microsilica and 800 kg/m^3 sand with a maximum diameter of 1 *mm*. This composition of the materials guaranteed a compact material structure where the fibres were quite perfectly embedded. The water-binder-ratio (w/b-ratio) was taken as low as possible to improve the strength, i.e. the w/b-ratio was 0.18. To keep the mixture self-compacting Glenium® superplasticizer was between 2.3% and 2.6% of the cement weight. The used fibres were Stratec steel fibres with different shapes and geometries. Straight steel wire fibres with a length of 6 and 12 *mm* and a diameter of 0.15 and 0.2 *mm* respectively and undulated steel fibres with a length of 30 *mm* and a diameter of 0.6 *mm* were used. The steel fibres had a tensile strength of 2400 MPa. Fresh concrete properties were tested using slump flow tests Stähli (2004) and the air contend was measured using the test according to EN 12350-7.

Table 1. Overview of the concrete mixtures

	3 0 0	0 3 0	0 0 3	1 1 1	3 1 1
Super-plasticizer [%]	2.0	2.0	2.6	2.0	2.3
Additional super-plasticizer [%]	0.3	0.3	-	0.4	0.3
0.15 x 0.6 mm fibre [Vol.-%]	3	-	-	1	3
0.20 x 12 mm fibre [Vol.-%]	-	3	-	1	1
0.60 x 27 mm fibre [Vol.-%]	-	-	3	1	1
Small slump flow [mm]	20.5	23	23	26	27
Large slump flow [mm]	62.5	67	78	76	84
Fresh concrete density [kg/m^3]	2428	2370	2378	2415	2503
Air content [%]	4	3.5	3.8	3.8	2.8

3 'PENDULUM-BAR' TENSILE TEST

3.1 *Operational principle*

The reason for using pendulum bars is based on the idea that during a tensile test the forces should remain centric and the supports should be able to rotate (Fig. 5 and 6). This becomes important especially when a material of increased ductility, such as HFC, is used. Van Mier (1994) showed that the boundary conditions in a uniaxial tensile test have a significant influence on the result of the test. The tensile strength but also the tensile strength obtained from uniaxial tensile tests between fixed boundaries are higher than the values received from tests with rotation supports. The centre of rotation of the supports is positioned at the centre of the interface between the specimen and the glued aluminium plates (Fig. 5).

The deformations are measured using four LVDT's, two at each side of the specimen as shown in Figure 7.

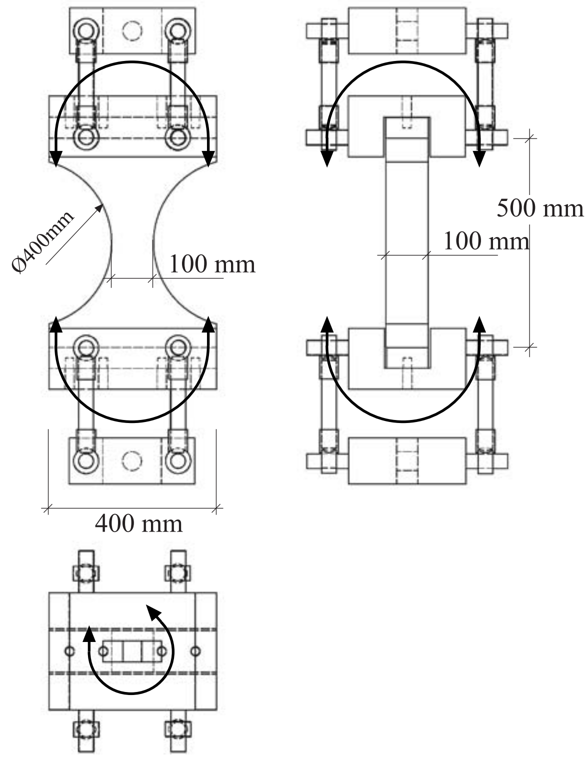


Figure 5. Sketch of the 'pendulum-bar' test set-up. The arrows shows the ability to rotate around the centre of rotation, e.g. arround the interface between aluminium plate and specimen. .

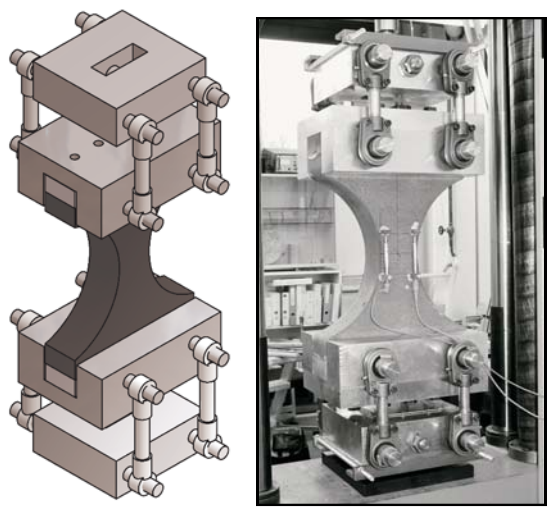


Figure 6. Sketch and image of the 'pendulum-bar' tensile test set-up.

3.2 *Specimen geometry*

To determine the uniaxial tensile strength of concrete, dog-bone shaped specimens are well proven (Markovic (2006), Van Vliet (2000), van Mier (1994), Carpinteri (1994)). In the presented experiments, the geometry of the specimen was derived by the maximum fibre length, the glue and the testing machine. The minimum cross section was at least three times the length of the largest fibre (30 mm). Therefore the dimension of the smallest cross section of the specimen is 100 mm by 100 mm.

The height of the tensile test specimen is 500 mm. The maximum width is 400 mm and, as mentioned, the minimum width is 100 mm. The chosen depth of the specimen was 100 mm. The radius of the curved sides is 200 mm. The capacity of the load cell used in the testing machine is 200 kN.

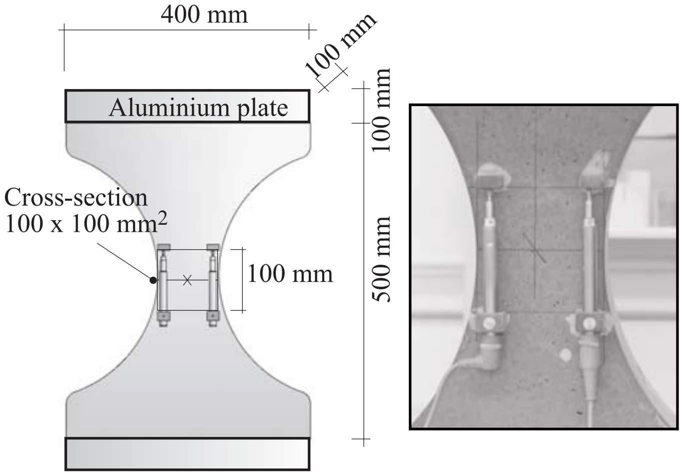


Figure 7. Sketch and photograph of the specimen and the attached LVDT's.

3.3 *Specimen preparation*

All the specimens were cast on one day with the same concrete batch. Two batches of 300 litres each of the same mixture per batch were produced on one day. All the presented results are those from the first of the two batches. For the whole series 3 m^3 fibre reinforced concrete was produced and cast. One day after casting, the specimens were demoulded, cut to the final geometry (Fig. 7, 8) and stored for the next 24 days in a climate chamber with a humidity of 95% and a temperature of 20°C. Three days before testing the samples were prepared for gluing. The surfaces of the specimen and the aluminium plates were ground, sand blasted and cleaned properly. Within two days, two aluminium plates with four M20 threads were glued to the top and the bottom of the specimen (Fig. 8). These plates were used to fix the sample in the tensile test rig. After one day the adhesive was fully hardened and the holders for the LVDT's were glued to each side of the specimen, after which the sample was ready to be tested.

4 RESULTS AND DISCUSSION

Figures 9 – 11 show results derived from the tensile test. It can be seen that the characteristics of the load displacement curves and the crack patterns are related. The figures also show that the curves from the four LVDT's can have completely different shapes. In Figure 9 the peak is very sharp. The same 'sharpness' can be seen in the crack pattern of this specimen. This crack propagated from the left to the right. After the peak, the deformations on the right side of the specimen decreases as expected. This behaviour is typical for a test set-up with freely rotating supports.

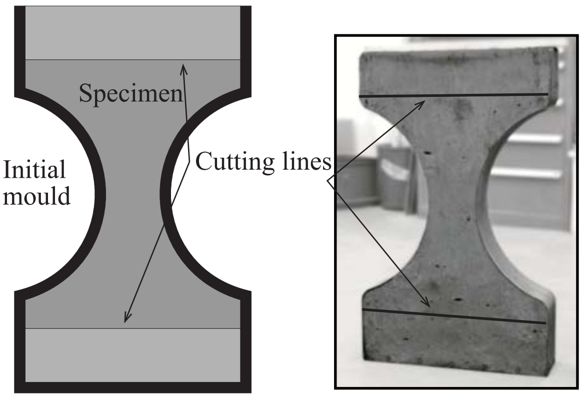
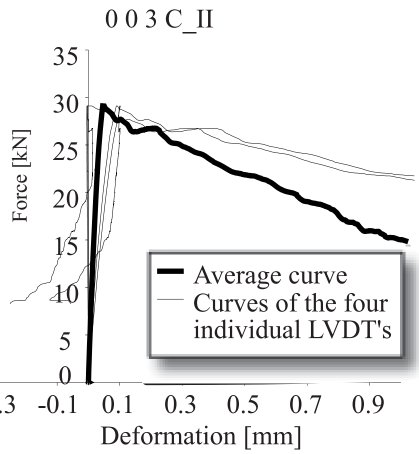
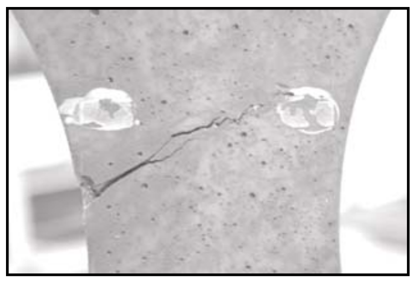


Figure 8.(a): An image of a tensile test specimen with its cutting lines. (b): The same specimen after gluing the aluminium plates.



(a)



(b)

Figure 9. (a): Curves derived by the pendulum-bar tensile test with the specimen 0 0 3 C_II. (b): Crack pattern of the above mentioned specimen.

Figure 10 shows a similar characteristic, but the deformation on the backside decreases now there the peak is very smooth. The crack propagated from the front to the backside of the specimen and its pattern is completely different. On the image of the crack pattern in Figure 10, it can be seen that there is not one single crack, but there is, typical for fibre reinforced materials, a crack zone with multiple cracking.

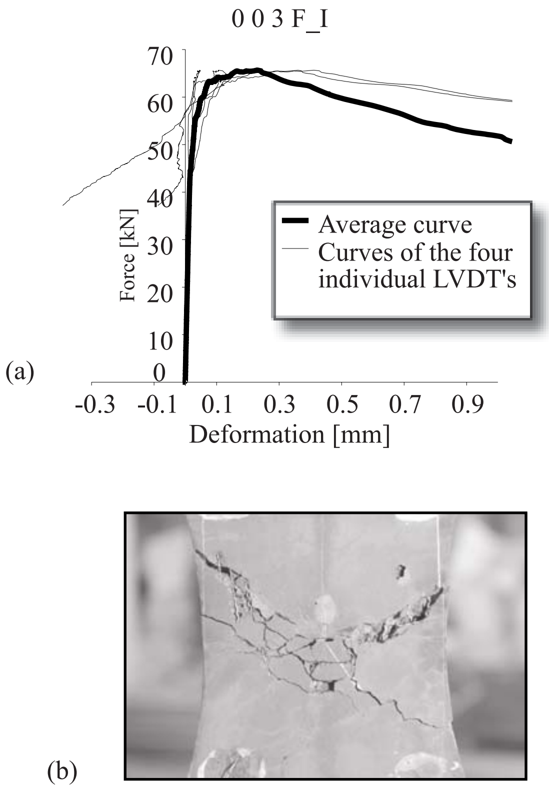


Figure 10. (a): Curves derived by the pendulum-bar tensile test with the specimen 0 0 3 F_I. (b): Crack pattern of the above mentioned specimen.

Figure 11 shows a third type of behaviour. The deformations of all sensors always increase during the tensile test. Here the whole cross-section is pulled symmetrically. The crack propagated from the left to the right and showed two branches. After cutting the aluminium plates from the sample with a water cooled diamond saw, white lines appeared on the surface of the specimen in the cracking zone. It seems that these white lines are micro cracks which can not be detected by the naked eye. Such phenomena also appeared on other specimens which are not reported in this paper.

The influence of the filling method for mixtures with one fibre only is significant. Figure 12 gives an overview of the results for the mixtures 3 0 0, 0 3 0 and 0 0 3. It can be seen that difference in the tensile strength for the conventional filling method is negligible. The tensile strengths are within the standard deviations. These standard deviations are relatively large in comparison to the ones from the two other filling methods. The fibre amount of these three mixtures was constant at 3%. The diagram also shows that the tensile strength for the 'filling' and the 'climbing' method is higher than for the 'conventional' method. This leads to the assumption that the tensile strength increases with the ability of flowing of the fresh concrete and with that the alignment of the fibres to the tensile direction. The longer the fresh concrete can flow, the higher the tensile strength is. This can be seen for all types of fibres, even for the small 0.15/6 mm fibres. But why does the tensile strength increase? To the author's opinion, the tensile strength increases because the fibres align with the flow of the material. This fact would explain the results from the current tensile tests. As seen before, when casting a specimen with the 'filling' method, the flow of the material is less than with the 'climbing' method, but the jump in tensile strength between 'filling' and 'climbing' method is not that large. It seems that the material does not need to flow that long; only a short, but controlled flow can increase the tensile strength significantly.

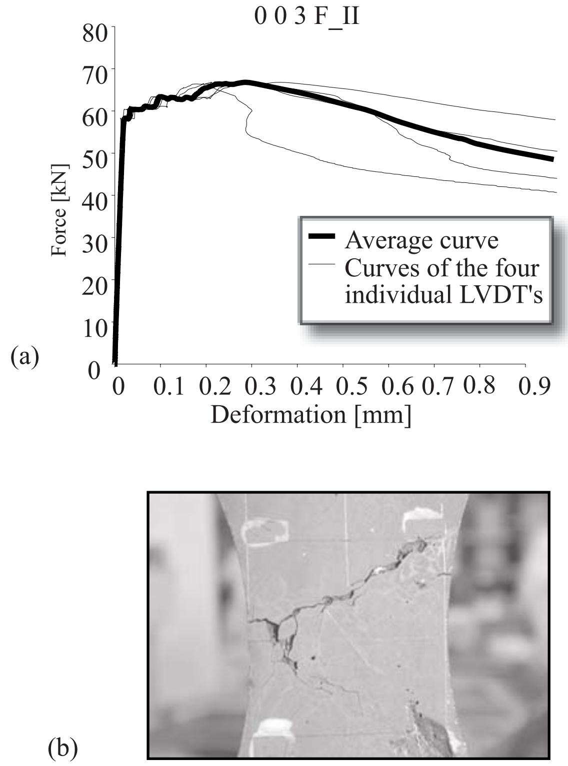
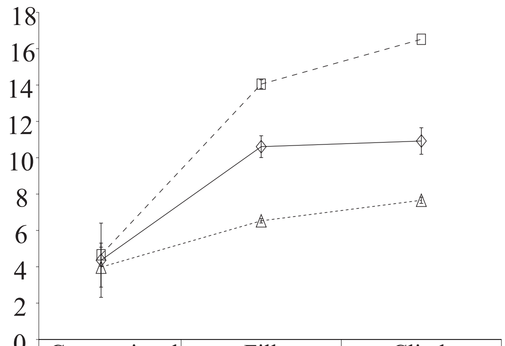


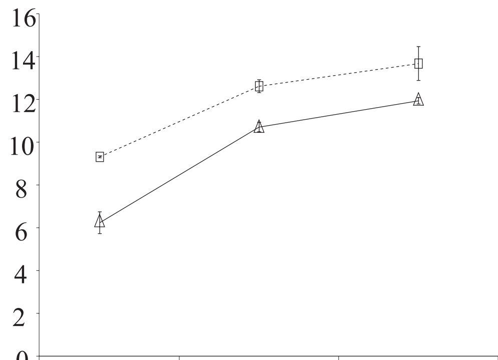
Figure 11. Upper: Curves derived by the pendulum-bar tensile test with the specimen 0 0 3 F_II. Lower: Crack pattern of the above mentioned specimen.

Figure 13 shows the summery of the results for the experiments with mixture 1 1 1 and 3 1 1. These two mixtures were both hybrid fibre concretes with three types of steel fibres. The fibre amounts were 3% and 5% for the mixtures 1 1 1 and 3 1 1 respectively. Both mixtures show that the tensile strength is dependant on the filling method. As seen before, the influence of concrete flowing results in an increasing tensile strength. Figure 13 also shows that the tensile strength for the mixture with 5% of fibres is higher then the one with 3% only. That means, by increasing the amount of fibres, the tensile strength increases as well. This was seen before in several studies, e.g. Markovic (2006).



	Conventional	Fill	Climb
3 0 0	4.36 (2.04)	10.61 (0.60)	10.92 (0.73)
0 3 0	4.66 (0.64)	14.05 (0.24)	16.52 (-)
0 0 3	3.98 (1.10)	6.53 (0.12)	7.66 (0.17)

Figure 12. Summery of the results in [MPa] derived from tensile test from the mixtures with only one type of fibre. The standard deviation is given in brackets.



	Conventional	Fill	Climb
1 1 1	6.23 (0.51)	10.7 (0.22)	11.93 (0.15)
3 1 1	9.31 (0.05)	12.61 (0.30)	13.67 (0.79)

Figure 13. Summery of the results in [MPa] derived from tensile test from the mixtures with HFC. The standard deviation is given in brackets.

5 CONCLUSIONS

- The filling method has a significant influence on the tensile strength (Fig 12 and 13). The presented results clearly show that the maximum tensile strength is dependant on how the material flows into the mould. The best results were obtained by filling the mould from the bottom to the top.
- The fibres align with the flow of the material.
- Rotation supports are a solution to test hybrid fibre concrete because with this method the freedom of movement is ensured during the whole test. In contrary to fixed supports, the obtained tensile strength results are real minima, and therefore safe to apply.
- Since the tensile properties depend on the flow of the concrete and the ensuing alignment of the fibres, conventional design methods cannot be applied. It is suggested that optimization of pre-cast elements is a sound future application of the effect described in this paper.

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