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INNOVATIVE STEEL FIBERS AND THEIR EFFECT ON FIBER DISTRIBUTION IN BEAMS – EXPERIMENTAL INVESTIGATIONS

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Abstract

This contribution presents experimental investigations on fiber reinforced concrete (FRC). A new type of straight steel fibers (company *Feel Fiber*) with a length of 60 mm was used. 12 beams with a length of 6 m, a height of 0.4 m and a width of 0.5 m were produced, in order to determine the fiber distribution along them. The beams differ in the manufacturing method (cast in layers or from one side), the fiber content and the way of fiber addition. After concretes hardening, slices were cut of the beams to determine the number of fibers in the cross section. The results showed that the number of fibers per unit area scatters about 10%, independent of manufacturing method and type of fiber addition. Finally, the results are discussed and a proposal to modify certain factors in the German and Austrian guideline for fiber reinforced concrete is made, to take the advantages of this new fiber type into account.

Streszczenie

W artykule zaprezentowano badania betonu zbrojonego włóknami (FRC). Zastosowano nowy typ włókien stalowych prostych (firmy *Feel Fiber*) o długości 60 mm. W celu rozpoznania jakości rozmieszczenia włókien w elemencie, wykonano 12 belek o rozpiętości 6 m, wysokości 0.4 m i szerokości 0.5 m. Belki różniły się sposobem wykonania (betonowanie warstwami lub z jednej strony), ilością włókien i sposobem aplikacji włókien. Po stwardnieniu betonu, belki przecinano w celu oceny dystrybucji włókien w przekroju poprzecznym. Wyniki badań wykazały, że ilość włókien przypadających na jednostkę powierzchni wykazuje rozrzut ok. 10%, niezależnie od metody wykonania i metody aplikacji włókien. Wyniki badań zestawiono i została przedstawiona propozycja zmian konkretnych współczynników w niemieckich i austriackich przepisach dot. betonu zbrojonego włóknami. Celem tych zmian jest ujęcie nowego typu włókien w przepisach.

Keywords: **Fiber reinforced concrete; Fiber distribution; Fiber orientation; Steel fiber; Beams.**

1. INTRODUCTION

The post cracking tensile behaviour of fiber reinforced concrete (FRC) scatters with about 20–25% as generally known. The large scattering influences the characteristic material properties as well as the safety factor negatively. As a result, fiber reinforced concrete is mainly used in components with high rearrangement capacity and relatively low load, such as floor slabs or tunnel shells. Investigations by [4, 5, 6] have shown that the large scattering in the post cracking tensile strength occurs in normal strength concrete and ultra high performance concrete, independent of fresh concrete properties. In [7, 8, 9] and [10], the fiber distribution and the fiber orientation are mentioned as reason for the large scattering. Especially the fiber orientation has been focused in the last years, as can be seen in [9, 10 and 11]. Different methods for positive influencing the of fiber orientation have been tested by [12, 13]. However these methods have proved to be

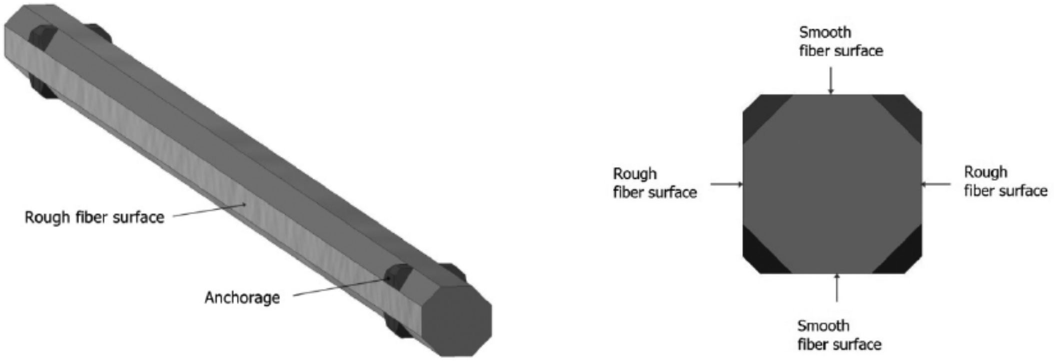

Figure 1.
Shape of the fiber

unpractical. Recent findings have shown that the inhomogeneous fiber distribution is mainly responsible for the large scattering in the post cracking tensile behaviour.

In this work, the influence of a new fiber type (company *Feel Fiber*) on the fiber distribution has been investigated. Fig. 1 demonstrates the *Feel Fiber* geometry schematically. It is characterized by anchorages at the end of the fiber and two rough sides as a consequence of the production process. The number, position and size of these anchors can be adapted according to the requirements.

One of the main advantages of this fiber is the straight fiber design. Thus, the influence on the fresh concrete properties should be smaller compared to hooked fibers. Consequently a more homogenous fiber distribution is expected and greater amounts of fibers can be used.

2. EXPERIMENTAL PROGRAM

The aim of the experiments was to investigate the fiber distribution in beams, depending on type of fiber addition, fiber content and manufacturing process. Beams with a length of 6 m, a width of 0.5 m and a height of ≈0.4 m were produced. The experimental program is shown schematically in Fig. 2.

Straight steel fibers with a length of 60 mm ($d_f \approx 0.75$ mm) and fiber contents of 30 and 60 kg/m^3, respectively, were used. Half of the beams were filled from one side, the other half was filled in layers. The fibers were added into a truck mixer by conveyor belt but varying the time of fiber addition. For the beams B1 to B4, the concrete was added in the truck mixer in advance and the fibers were added afterwards. In contrast to this, the steel fibers for beams B5 to B8 were completely added in the mixer before the concrete was filled. Beams B9 to B12 present a third fiber addition procedure. In this process the fibers and the concrete were alternately added in several steps. One beam was produced for each fiber addition procedure, fiber content and filling method.

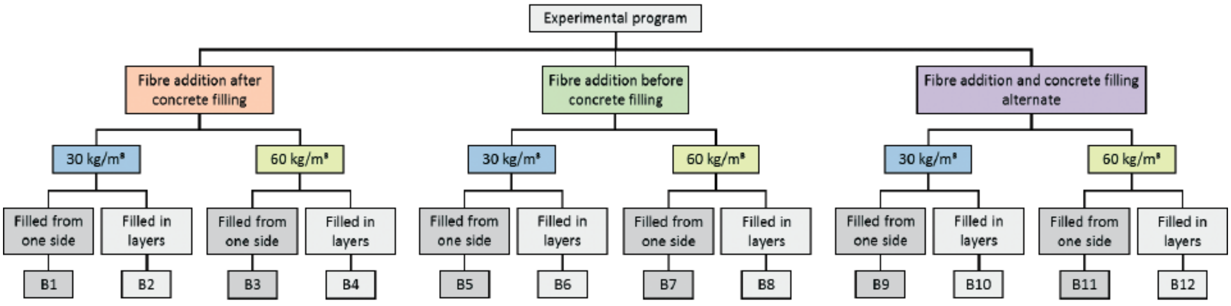

Figure 2.
Experimental program

Figure 3.
Fiber addition via conveyor belt (left) and filling of the beam from one side (right)

3. EXPERIMENTAL SETUP AND PROCEDURE

The used concrete is classified as a C30/37 with a maximum grain size of 16 mm. The amount of paste got increased for the mixtures with a fiber content of 60 kg/m^3, in order to keep the consistency constant for all test series. The mixing time of the truck mixer was always 8 min. Two beams were produced with one load of the truck mixer. All beams were compacted with an internal vibrator at predefined points (distance between points 30 cm).

Six slices were cut from each beam to determine the number of fibers in different cross sections. The thickness of the slices was 70 mm, in order to get two independent cuts by using 60 mm fibers. The number of fibers was counted on the front side and on the back side of the slices. Hence, a total of 12 cross sections were investigated for each beam. Fig. 4 shows the configuration of the cuts as well as the vibration points.

The fresh concrete properties were tested parallel to the casting of the beams. The flow spread was determined accordingly to DIN EN 12350-5. Furthermore, the fiber distribution in the fresh concrete was carried out accordingly to the German guideline for steel fiber reinforced concrete (washout-test). Three fresh concrete samples (10–15 liters) were taken from the truck mixer (one of every third of the batch). By measuring the fresh concrete density, according to DIN EN 12350-4 and the weight of the partial samples, it is possible to determine the volume of the partial sample. After separating the fibers from the fresh concrete by magnet, the mass of the steel fiber as well as the steel fiber content of the sample could be determined.

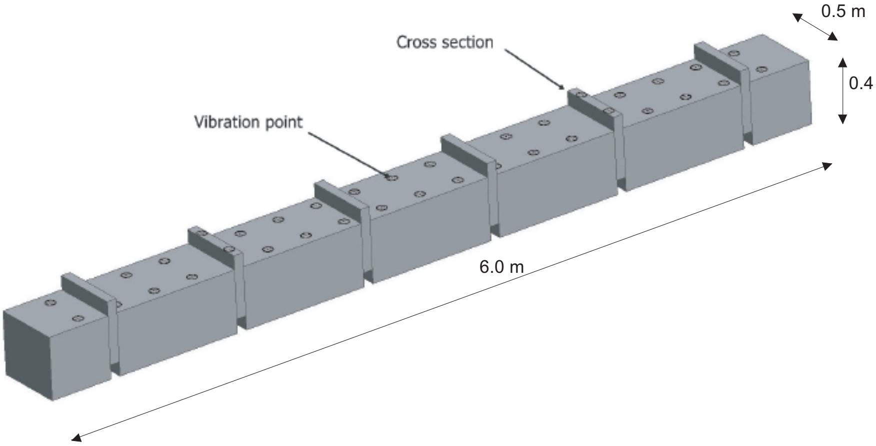

Figure 4.
Beam and configuration of the cuts

Figure 5.
Determination of the flow spread (left) and separation of steel fibers from the fresh concrete (right)

4. EXPERIMENTAL RESULTS

4.1 Properties of fresh concrete

The mixtures with a fiber content of 30 kg/m³ as well as those with 60 kg/m³ showed a good flowability of the fresh concrete. The flow spread was in a range of 540 to 630 mm. The results of the washout-test are shown in Tab. 1. According to the DAfStb guideline for steel fiber reinforced concrete [1], the following conformity criteria must be observed:

- Single value criteria: $m_{f,i} \geq 0.80 \text{ x } m_{f,ziel}$
- Mean value criteria: $\bar{m}_f \geq 0.85 \text{ x } m_{f,ziel}$

The criteria according to [1] were fulfilled for all mixtures. Furthermore, the coefficient of variation (V = standard deviation / mean value) has been determined, as it can be seen in Tab. 1. The scattering is in a range of 1–7%. On the basis of these small scatterings, a good fiber distribution in the mixer can be expected for all fiber addition procedures.

It is worth mentioning that the sample quantity of 15 litres corresponds to one entire standard bending beam. Therefore this method does not make it possible to reproduce the scattering in the local bearing behaviour of standard beams. Due to this fact, it is proposed in [2] to determine the sample quantity as a function of the component geometry.

Table 1.
Fiber distribution in the fresh concrete

		Fiber content $m_{f,i}$ [kg/m³]	Mean value criteria $\bar{m}_f$ [kg/m³]	Variation coefficient [%]	Fiber content $m_{f,i}$ [kg/m³]	Mean value criteria $\bar{m}_f$ [kg/m³]	Variation coefficient [%]
		$m_{f,ziel}$ = 30 [kg/m³]			$m_{f,ziel}$ = 60 [kg/m³]		
Fiber addition after concrete filling	1. sample	30.3	30.6	0.9	63.1	65.4	4.5
	2. sample	30.7			68.7		
	3. sample	30.8			64.4		
Fiber addition before concrete filling	1. sample	31.0	31.2	6.8	60.9	65.1	5.9
	2. sample	33.4			65.9		
	3. sample	29.2			68.5		
Fiber addition and concrete filling alternate	1. sample	30.9	31.4	1.9	68.9	64.8	5.6
	2. sample	32.1			63.1		
	3. sample	31.3			62.3		

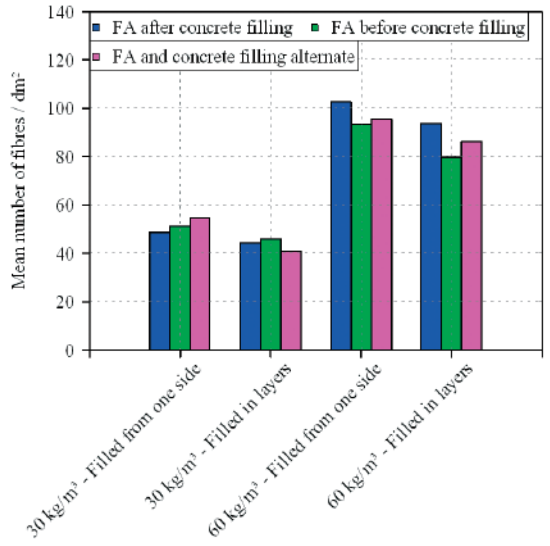

Figure 6.
Mean number of fibers in the cross sections

4.2. Fiber distribution in beams

The number of fibers was counted in each cross section of the beam. The mean number of fibers per cross section [number of fibers / dm^2] is shown in Fig. 6 for each beam.

It has to be mentioned that the number of fibers in the cross section depends essentially on the fiber orientation in the component. As shown in Fig. 6, a smaller mean number of fibers was determined in beams which were filled in layers, compared to beams, which were filled from one side. This indicates that the fibers align along the flow direction. Consequently, more fibers cross the beam section. A mean fiber orientation $\eta \approx 0.55$–0.60 could be determined in beams filled from one side, according to the equation of [14] and the model of [2]. For beams, which are filled in layers, a three-dimensional fiber orientation of about $\eta \approx 0.50$ was obtained. The determined values corresponds to the statements, which are given by [3, 7] and [15].

The fiber distribution was calculated, based on the number of fibers in the 12 cross sections. Therefore, the coefficient of variation was determined as shown in Fig. 7. It can be seen that the number of crossing fibers scatters in a range of 7–12%. This constitutes a low scattering in view of test series by [2] and [15] and with comparable fiber addition procedures, where variation coefficients of ≈15% could be determined.

Fig. 7 shows that no fiber addition procedure tends to a larger scattering. But they show a tendency, that beams which are filled in layers, lead to a more homogenous fiber distribution than beams cast in layers.

As demonstrated, the new fiber type leads to a relatively low scattering of the fiber distribution, independent of fiber content, filling method and type of fiber addition.

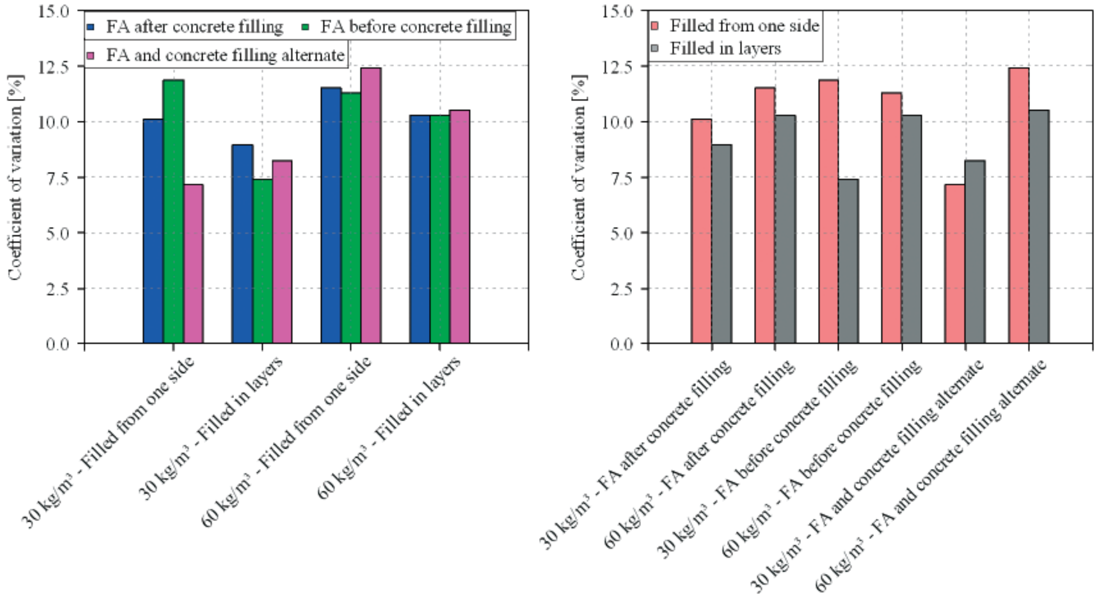

Figure 7.
Scattering of the number of crossing fibers – Comparison of the fiber addition procedures (left) and the filling method (right)

5. CONCLUSIONS AND FUTURE PROSPECTS

This contribution presents the results from an investigation on the effect of a new straight fiber type on the fiber distribution in beams. The influence of the fiber addition procedure, the fiber content and the filling method were additionally investigated. The presented results show that the number of fibers in the cross section of the beams, scatters about 10%, independent of the manufacturing procedure.

The German as well as the Austrian guideline for fiber reinforced concrete, define 4-point-bending tests for the determination of the material properties. In order to obtain the characteristic value of the flexural tensile strength (5% – quantile), the mean value is reduced by a factor of 0.51, which corresponds to a variation coefficient of about 25%. However, the advantage of a more homogenous fiber distribution cannot be taken into account with this limitation. As shown in [2], a scattering of 15% increases the factor from 0.51 to 0.7, which means that the design value of the post-cracking tensile strength is increased by the factor 1.4.

Regarding the further development of this steel fiber type and its influence on the fiber distribution, an additional experimental program is planned. The future program includes beams, basements and rising walls in order to consider realistic conditions. Small specimens according to the German guideline for fiber reinforced concrete will be cut from beams, basements and walls after casting. Subsequently 4-point-bending tests will be performed, to obtain the realistic load bearing behaviour of the component. To gather information on the fiber orientation and distribution, slices will be cut from selected specimens after its bending test. By using an opto-analytic method the fiber orientation and distribution will be determined.

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