CEMEX Deutschland AG, 40880 Ratingen, Germany

Quality assurance of steel fibre reinforced concrete in ready-mix concrete plants

Steel fibre reinforced concrete has caught on in a large number of applications. These applications include tunnel construction, industrial floor construction, foundation slabs or components requiring extremely high wear resistance. The scope of application (components, structures) and the application depth (limitation of the crack width to ensure suitability for use and durability) of steel fibre reinforced concrete will become more important in Germany due to the "Steel fibre reinforced concrete" directive of the Deutscher Ausschuss für Stahlbeton which is almost complete, as well as through current and forthcoming approval notification.

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It is important for the material applications, that the defined steel fibre reinforced concrete material characteristics from the structural planning and dimensioning assumptions are used during manufacture and construction. The quality chain "Dimensioning - design - manufacture - implementation" must be guaranteed. - On the other hand steel fibre reinforced concrete must remain economically viable. Extremely high quality assurance requirements would lead to an economical "knock out" of the state of the art building material.

A quality assurance concept, that takes this situation into account, consists of the determination of the post-fracture behaviour (especially the post-fracture tensile strength) by carrying out a beam-bending test (**fig. 1**) for evaluation and classification of it's capacity as well as a continuous quality control and correction in the production and if necessary during construction through determination of fibre content.

Capacity determination by means of a fracture test

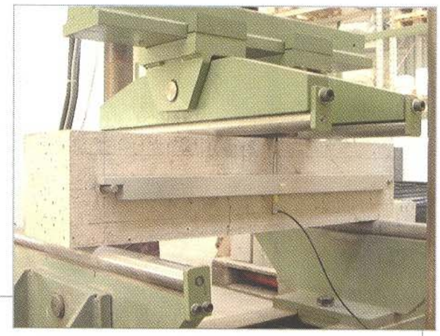
Steel fibre reinforced concrete is a concrete with a particular characteristic. The particular characteristic lies in the post-fracture bending tensile strength or post-fracture tensile strength. This characteristic is obtained through the addition of steel fibres (**fig. 2**). The fibre content for most applications is between 20 and 40 kg/m³; which represents 0.25 to 0.51 % in vol.

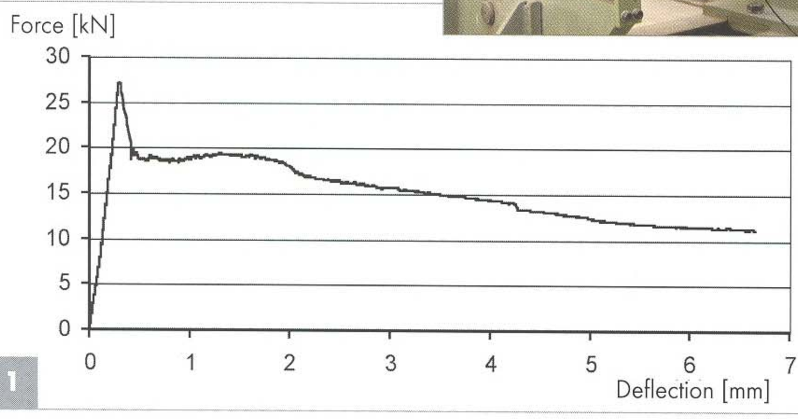
The capacity of steel fibre reinforced concrete is assessed on each one of six bending-beams of 700 mm long x 150 mm wide x 150 mm high. The bending-beams are loaded in a 4-point bending test (**fig. 1**). The results of the test are force-displacement curves, whereby the displacement of the bending - beam is usually taken as the deformation factor. Bending tensile stresses are specified with the help of the measured force and bending-beam cross section. The curve is analysed currently according to the DBV-data sheet [4] or, after an approval has been granted (e.g. [1]), by calculation of the physical work (area integral).

If the capacity of a steel fibre reinforced concrete is to be used, it must be determined from initial testing according to EN 206-1 [7] and DIN 1045-2 [8]. The post-fracture tensile strength ranges between 0.4 N/mm² and 2.0 N/mm² and depends on various factors such as fibre content, fibre type (see [5]) The post-fracture tensile strengths can be classified (see [2, 4, 5]).

Determination of fibre content as a new approach

Proceed as follows when making steel fibre reinforced concrete for the first time





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Top right: Mechanical post-fracture beam-bending test for determination of the post-fracture bending tensile strength of steel fibre reinforced concrete;
Below: Test result as a force-displacement curve (example)

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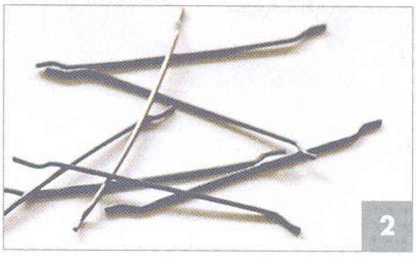
in a ready - mix concrete plant: First of all you need to define the specified class of the steel fibre reinforced concrete (or capacity class). A specific amount of fibres are added to obtain the specified steel fibre reinforced. The concrete's theoretical capacity classification is confirmed during the initial beam-bending tests (see above). No changes are made to the fibre content.

The traditional quality assurance approach was to carry out regular tests on the steel fibre reinforced concrete by carrying out mechanical fracture beam-bending tests. This is a very elaborate method and requires a lot of time and test equipment. The results are only determined for the first time after 28 days.



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Steel fibres for concrete (exemplary fibres with bent ends; length 50 mm and diameter 1 mm)

The new quality assurance approach consists of regular testing of the fibre content. Since the fibre content of a specified concrete does not change, it must be proven by a certain frequency that the actual fibre content in the concrete concerned (actual fibre content) corresponds with the specified fibre content (nominal fibre content) according to the initial testing. This is carried out by determination of the fibre content.

Methods for determination of fibre content

There are different methods for determining the fibre contents. These include:

- Crushing of hardened concrete test pieces
- Leaching out of fresh concrete (if necessary with magnetic separation)
- inductive measurement on fresh or hardened concrete.

The methods are introduced in the following sections. Evaluation criteria for conformity are given in the following sections.

Crushing of hardened concrete test pieces

Hardened concrete test pieces are crushed for determination of fibre content of hardened concrete (**fig. 4**). The hardened concrete test pieces can be bore cores or cubes (e. g. with a length of 15 cm). The volume of the test pieces must be determined. The test pieces are to be crushed with a pressure testing machine or other suitable device in order to separate the fibres from the concrete. The fibres can be collected by hand or with a magnet. The collected fibres must be thoroughly cleaned and weighed. The fibre content m_{SF} is to be calculated from the mass of the fibres M_{SF} and the volume of the sample VSample-$_{SF}$ in accordance with the following formula:

$$m_{SF}\,[kg/m^3] = \frac{M_{SF}\,[kg]}{V_{SF}\text{-Sample}\,[\,l\,]} \cdot 1000\ [l/m^3] \quad (1)$$

3

Leaching out test

Leaching out of fresh concrete

The steel fibre content determination of fresh concrete is carried out by the leaching out of a fresh concrete sample of a certain volume (**fig. 3**). The sample is then dried, the steel fibres are separated and their mass determined. An air void test device with a volume of 8 litres is usually used as a sample container. The samples are filled into the air void test device; where they are compressed and spread evenly. The leached out samples can either be placed in a drying cabinet or dried on a kiln, in order to ease the separation of the steel fibres from the mixture. Drying with a cloth is adequate enough for the accuracy. The sample fibre content is calculated according to formula (1).

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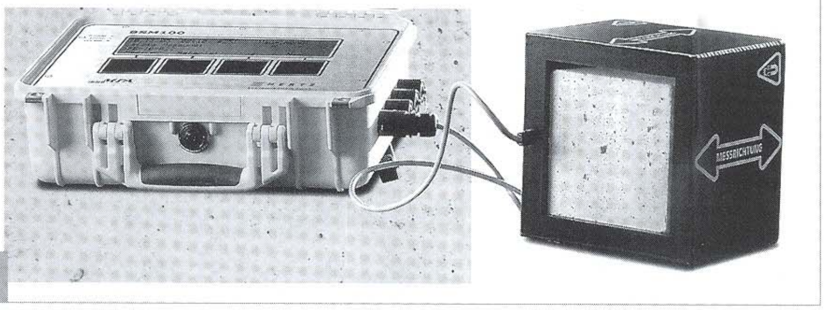
Fibre content determination by crushing hardened concrete test pieces

Inductive measurement

A box with current carrying coils is used for the tested inductive measurement method [9] (**fig. 5**). The box is designed for a cube with an length of 150 mm. The magnetic field created by the coils changes due to the steel fibres in the concrete. The fibre content can be read off directly due to the change in the magnetic field, if the inductive measurement device is calibrated for the steel fibres used.

Advantages and accuracy of the method

The methods for fibre content determination are much easier and faster for carrying out quality inspection and control than the bending-beam test. The test results are available quickly; immediately in the case of leaching out tests and inductive measurements.
The accuracy of the "Crushing of hardened concrete tests pieces" method, is given as 5 % in paragraph 3 of EN14721 [3] due to the loss of fibres. An accuracy of 1 kg/m³ [9] is given by the manufacturer for the inductive measurement method which equals 5 % for a fibre content of 20 kg/m³.



Inductive measurement of fibre content (of a hardened concrete sample [9])

Fibre content for verifying conformity

The conformity between the concrete's characteristic and the specification are checked against certain conformity criteria. In the case of steel fibre reinforced concrete the conformity is verified using the fibre content method additionally to the usual conformity criteria for concrete such as compression strength and consistency.

Characteristic values are laid down as conformity criteria. These can be can be lower, mean or upper quantile values. The given characteristic values in the current building authority approval [1] can be seen as mean quantile value. For adequate batch sizes only 95% of the nominal fibre content is to be verified, due to the testing tolerance fibre loss of 5 % (see above; [3, 9]). An adequate batch size is at least 15 mobile mixer loads. For the batch size of one mobile mixer a relative actual fibre content (ration of actual to nominal fibre content) of at least 85 % is to be verified. In addition the relative actual fibre content must be above 80% in the case of partial quantities from mobile mixers. With this lower limit (**see fig 6**) exists a statistic analogy to the individual value criteria "f_{ck} – 4" of the compression strength. A value of f_{ck} - 4 N/mm² also represents 0.8 times the nominal value for C20/25 concrete.

Aim of the investigations

There are a total of three questions to pose about the actual situation in construction practice:

1. How is the quality level of the steel fibre reinforced concrete that will be delivered as ready-mix concrete?
2. Is the homogeneity of the mixture worse in one part of the mobile mixer compared to another?
3. How big is the distribution of fibre content within a mobile mixer?

Answers to these three questions are discussed below.

Test results in construction practice

Mobile mixer sampling

Sampling was carried out by CEMEX Deutschland AG, throughout Germany from march 2005 until May 2006, for their own data evaluation and quality control checks. One partial sample each was removed from the first third, second third and final third (**fig. 7**) of the mixer load and the actual fibre content checked.

A total of 99 mobile mixers were checked. The random sampling captured different fibre content addition processes, vehicles with different load quantities as well as concrete with different consistencies with varying fibre types and contents:

- The following process was used for the addition of fibres: Addition onto the aggregate conveyor belts (on the aggregates themselves); addition into the mixer in the mixing tower or in-plant addition into the mobile mixer drum (using fans for example).
- The load quantities varied between 2.25 m³ and 10 m³; the average value was 7.8 m³ per mobile mixer.
- The slump-consistency was between 450 mm and 690 mm (F3 to F6 consistency class according to [7, 8]).
- The different types of fibres varied in length from 45 to 60 mm and from 0.75 to 1.0 mm in diameter.
- The fibre content was 20 to 40 kg/m³ (nominal fibre content).

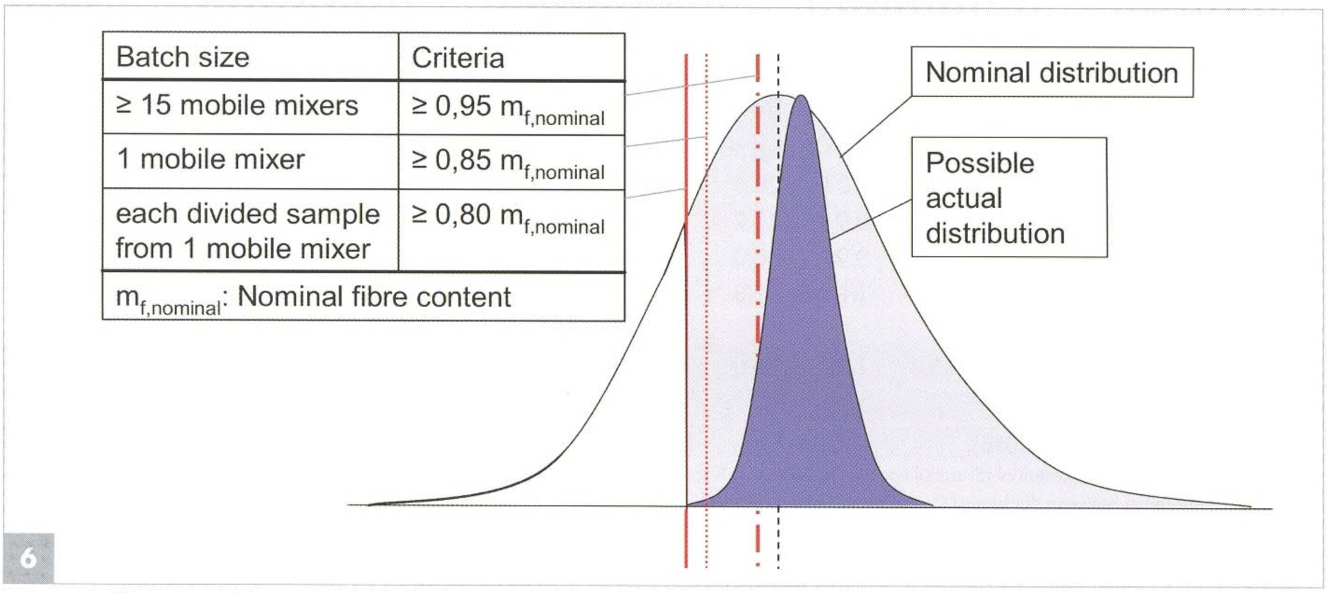
Note: Not all the information was available from the ninety nine mobile mixer samples.

Batch size	Criterion No.	Criterion Requirements
≥ 15 mobile mixers	1	$\geq 0.95 \cdot m_{f,nominal}$
1 mobile mixer	2	$\geq 0.85 \cdot m_{f,nominal}$
Each partial sample 1 mobile mixer	3	$\geq 0.80 \cdot m_{f,nominal}$

$m_{f,nominal}$: nominal fibre content

Note:
The requirement of at least 0.95 $m_{f,nominal}$ is valid in accordance to the DafStb-directive [2] and a value of at least 0.90 · $m_{f,nominal}$ for criterion 1 which is for the continuous production (≥ 15 mobile mixers) and initial production (3 mobile mixers).

Table 1 - Criteria for the fibre content test according to the approval granted [1] and according to the design of the DafStb-directive for fibre steel reinforced concrete [2]



Batch size	Criteria
≥ 15 mobile mixers	$\geq 0{,}95\ m_{f,nominal}$
1 mobile mixer	$\geq 0{,}85\ m_{f,nominal}$
each divided sample from 1 mobile mixer	$\geq 0{,}80\ m_{f,nominal}$
$m_{f,nominal}$: Nominal fibre content	

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Schematic illustration of the evaluation criteria for the fibre content test and possible actual distribution of the concrete production

The container sizes for the partial samples varied in size between 5 and 8 litres. The geographical area from the north of Germany to the east of Germany or from the west of Germany to the south of Germany was covered.

Quality level results

The actual fibre content was based on the nominal fibre content in order to better analyse the samples (columns 4, 6, 8 and 10 in **table 2**). A statistical classification into ten classes was made to give an overview of the sampling (answer to the first question). Number of and range of classes were determined according to [6]. The frequency of each class is displayed on a histogram (**fig. 8**). The highest frequency appeared at class 102 %. The frequency distribution can be assumed to be normal (**fig. 8**). The mathematical average of the relative actual fibre content from all mobile mixers sampling was 1.02 (see column 10, row 11 in **table 2**). The answer to question one about quality level can be confirmed by saying that the actual fibre content on average is slightly above the nominal value of the concrete.

Uniformity results

To answer the second question, only the first partial sample from each of the 99 mobile mixers sampled was taken into account and the mathematical average value calculated (column 4 in **table 2**). The same procedure was followed for the second and third partial sample. The results are summarised in **table 2**. The result each time was 1.02. From this it can be deduced that no systematic increase or decrease of fibre content takes place in any part of the mobile mixer. There is only a minimal difference when you calculate to more decimal places which are beyond the tolerance limit anyway (row 12 in **table 2**)

To answer the third question, the distribution is defined as a spread. The spread is the difference between largest and smallest partial sample value of a mobile mixer. The individual spreads are calculated for the overall random sampling scope. The average value of the spread for ninety nine values is 0.14 (see also **table 2**, column 14, row 11). The average spread can be expressed as a positive or negative deviation. This results in a deviation of ± 0.07, which can be estimated as the average variance of the mobile mixers. This average deviation of ± 0.07 represents a variation of ± 2 kg/m³

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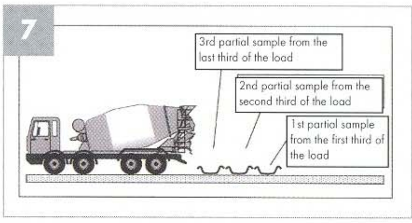


Removal of three partial samples from one mobile mixer

at 30 kg/m³. This is relatively low. The uniformity of ready-mix concrete delivered from mobile mixers with steel fibre reinforced concrete can be regarded as high.

Summary

Fibre content determinations are suitable and effective measures for production control and quality inspections of steel fibre reinforced concrete. The sampling throughout Germany of 99 mobile mixers resulting in a high quality. The actual fibre content on average is slightly above the nominal value of the concrete.

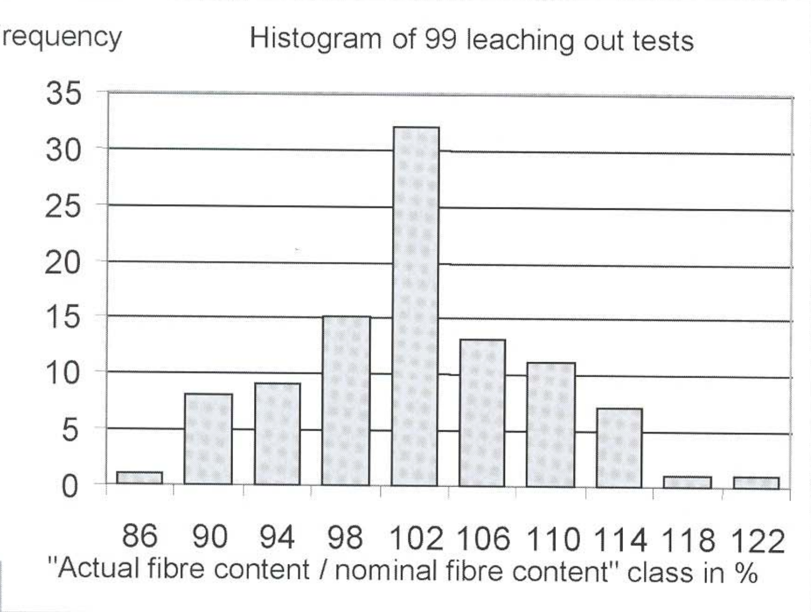
The fibre content exhibits a statistical distribution which is similar to that of other concrete properties such as compression strength. With regard to the distribution of steel fibres in mobile mixers it was shown in the presentation of the results, that there was no apparent systematic increase or decrease of fibre contents in the first, second or last part of the load. Further the partial samples evaluation showed that the average deviation of fibre content within a load has a value of ± 0.07 for a fibre content of 30 kg/m³ which means a difference of ± 2 kg/m³. The uniformity of ready-mix concrete delivered from mobile mixers with steel fibre reinforced concrete can be regarded as high. A pre-requisite for this is that the fibre addition is made in the ready-mix concrete plant.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	seq.	ACTUAL	1)	ACTUAL	1)	ACTUAL	1)	ACTUAL	1)	NOMI-	min	max	Spread 2)
3	No.	PS 1st third		PS 2nd third		DS last third		Average value		NAL			„max – min"
4		kg/m³	%	kg/m³	%	kg/m³	%	kg/m³	%	kg/m³	%	%	%
5	1	32.8	1.09	31.0	1.03	28.5	0.95	30.8	1.03	30	0.95	1.09	0.14
6	2	42.1	1.05	38.1	0.95	40.2	1.00	40.1	1.00	40	0.95	1.05	0.10
7	3	33.6	0.96	32.8	0.94	40.0	1.14	35.5	1.01	35	0.94	1.14	0.20
8	4	29.3	0.98	33.7	1.12	30.8	1.03	31.3	1.04	30	0.98	1.12	0.14
9	:	:	:	:	:	:	:	:	:	:	:	:	:
10	99	24.2	0.97	25.6	1.02	26.0	1.04	25.3	1.01	25	0.97	1.04	0.07
11	avg.		1.02		1.02		1.02		1.02				0.14 3)
12			(1.018)		(1.019)		(1.023)						

1) The relative actual fibre content of all samplings was not below 0.8 for any partial sample and not below 0.85 for any mobile mixer.
2) Spread: Difference between the largest ("max") and smallest partial sample values ("min") of a mobile mixer.
3) A spread of 0.14 means a variation of ± 0.07.

Abbreviations: PS: partial sample avg.: average

Table 2 - Result of the fibre content determinations



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Frequency of classes of "Actual fibre content / nominal fibre content" in the mobile mixer sampling carried out throughout Germany

These investigations confirms the approa-ches found in the granted approval and in the DafStb-directive.

Further information:

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Literature

[1] Deutsches Institut für Bautechnik: Allgemeine bauaufsichtliche Zulassung Z-71.3-24 „Readymix Fundamentplatten aus Stahlfaserbeton", 08.11.2005, CEMEX Deutschland AG, Ratingen

[2] Deutscher Ausschuss für Stahlbeton: Richtlinie Stahlfaserbeton. 22. Entwurf September 2005, Berlin.

[3] prEN14721: Prüfverfahren für Beton mit metallischen Fasern – Bestimmung des Fasergehaltes in Frisch- und Festbeton, März 2005

[4] Deutscher Beton- und Bautechnik-Verein (DBV): Merkblatt „Stahlfaserbeton"; Berlin, 2001

[5] Alfes, C; Sigrist, V.: Einfluss der Betondruckfestigkeit auf die Leistungsfähigkeit von Stahlfaserbeton. Beton 3/2006, S. 82-87, Verlag Bau + Technik

[6] Wesche, K.: Baustoffe für Tragende Bauteile. Band 1 Grundlagen. Bauverlag Wiesbaden und Berlin, 3. Auflage 1996

[7] DIN EN 206-1: Beton – Teil 1: Festlegung, Eigenschaften, Herstellung und Konformität. Beuth Verlag, Berlin, 2001

[8] DIN 1045-2: Tragwerke aus Beton, Stahlbeton und Spannbeton – Teil 2: Beton – Festlegung, Eigenschaften, Herstellung und Konformität; Anwendungsregeln zu DIN EN 206-1. Beuth Verlag, Berlin, 2001

[9] Produktinformation BSM 100 der Hertz Systemtechnik, Delmenhorst