NON DESTRUCTIVE DETERMINATION OF STEEL FIBER DOSAGE AND FIBER ORIENTATION IN CONCRETE SAMPLES

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Abstract

Steel fiber reinforced concrete is nowadays frequently used in civil engineering and the building industry. Apart from the general state of the concrete, the dosage and the distribution of the steel fibers are of prime importance for the quality of the structure.

During the last years, a new method to determine both the steel fiber dosage and steel fiber orientation has been developed at the Institute for Building Materials, Concrete Structures and Fire Protection (IBMB) at the University of Braunschweig [1] [2, [3] . In cooperation with an industrial partner a market-ready measurement system has been produced.

The new method makes use of the magnetic induction of ferromagnetic materials. By means of a cube shaped sensor consisting of two coils samples of fresh and of hardened concrete as well as drilling core samples from existing structures can be analyzed. Fresh concrete is put into a cubic container for examination. Drilling core samples taken from structures can be examined directly. In the contribution the measurement principle and sensor design as well as lab-made test results and the experience of first on site-applications will be discussed.

Keywords: Steel Fiber Reinforced Concrete, Electromagnetics, Concrete Durability, Monitoring, Quality Control

1.1.1.1

2. Introduction

Steel fiber reinforced concrete is nowadays frequently used in civil engineering and the building industry. Apart from the general state of the concrete, the dosage and the distribution of the steel fibers are of prime importance for the quality of the structure.

The current standard methods to determine the fiber dosage (using a magnet after wash-out) and the fiber orientation (examining polished cut images) are complicated, time-consuming and expensive. In order to determine the steel fiber dosage in drilling cores, the samples have to be destroyed. A better, reliable non-destructive and competitive method is high in demand to supervise the steel fiber dosage not only during the production of new structures and buildings but also to examine drill-core samples from damaged structures.

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3. Basics

The magnetic properties of ferromagnetic materials in an alternating magnetic field are described by the hysteresis loop (see fig. 1). It shows the dependency between an (externally applied) magnetic field $\vec{H}$ and the resulting magnetic flux density $\vec{B}$ for ferromagnetic and non-ferromagnetic materials.

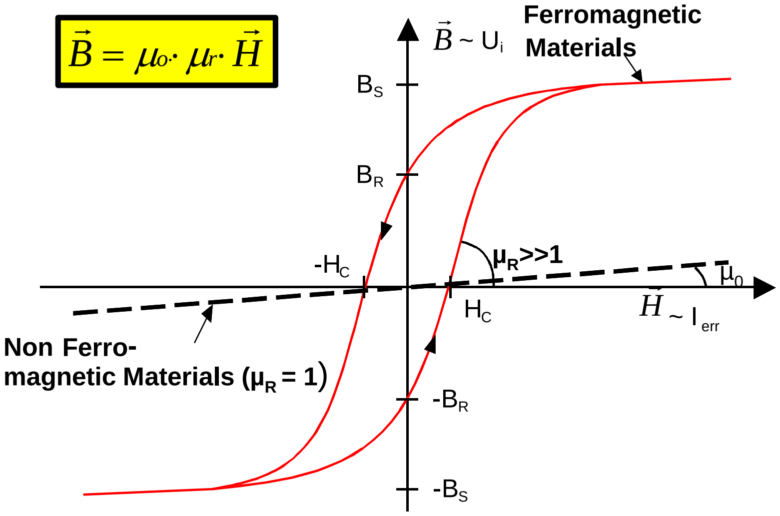

Fig. 1: Hysteresis loop

If an alternating magnetic field is applied to a ferromagnetic material, the resulting magnetic flux density $\vec{B}$ increases non-linear to the magnetic field strength $\vec{H}$. During demagnetisation, the downward sloping curve does not follow the original magnetisation curve. The resulting curve for all strengths of the magnetic field is a loop in an S-shape.

The slope in the zero crossing of the hysteresis curve is defined as magnetic permeability $\mu Rges = \mu r * \mu_0$. The relative permeability μ_r is the ratio of a specific material to the permeability of free space, the magnetic constant μ_0. It is

$$\mu_o = 4\,\pi 10^{-7}\ \text{Vs/Am} = 1{,}2566 \times 10^{-7}\text{Vs/Am} = 1{,}2566\ \mu\text{Henry/m}.$$

Only ferromagnetic materials (iron, cobalt and nickel) have a permeability μ_r >>1, for other materials the permeability $\mu_r \approx 1$. These materials have no hysteresis loss, so no hysteresis curve is created. The gradient of the plotted line is μ_o.

Steel fiber concrete consists almost only of materials with a permeability $\mu_r \approx 1$. Only the steel fibers, mostly being made up of iron, have a permeability μ_r >> 1, so different concrete mixtures or water/cement ratios do not influence the slope of the hysteresis curve.

4. Measuring principle

The dosage of steel fibers in a concrete sample can be gauged by the so-called transformer principle.

Figure 2 shows the fundamental test assembly. In this case, one coil is used to excite the magnetic field and another outer coil is used to create the induced voltage U_i . The induction coil is smaller than and completely enclosed by the operating winding. A fresh or hardened concrete sample takes over the function of the core of the coil. A sine-shaped alternating current I_{err} is fed into the operating winding from the regulated generator G and the induced voltage U_i in the induction coil is gauged.

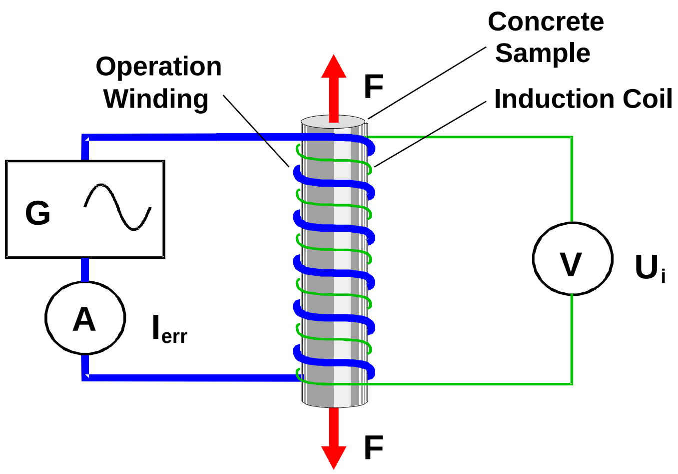

Fig. 2: Test assembly for the measurement of magnetic characteristics

The amplitude and frequency of the alternating current I_{err} are kept stable using a closed-loop control, so the induction voltage U_i is only depending on a change of the magnetic permeability (the type of steel fiber) and the amount of steel fibers in the sample.

5. Measurement procedure

Figure 3 shows the cube shaped sensor that is used for samples of fresh and hardened concrete.

Fig. 3: Sensor

The measurement procedure requires four single measurements. The first measurement is done using the empty sensor to determine the induction voltage of the empty sensor. For measurement with fresh concrete, the concrete is filled into a special plastic box with inner space dimensions of 15x15x15cm. The box is put in the sensor to carry out the measurement. The measurement is repeated in all three directions in space (see fig. 4), either turning the sample or the sensor. Samples of hardened concrete (test cubes and drilling cores) can be analyzed directly (fig. 5).

To determine the steel fiber dosage of the sample, the average of the three measurement results is subtracted from the result of the empty sensor.

Fig. 4: Box for fresh concrete

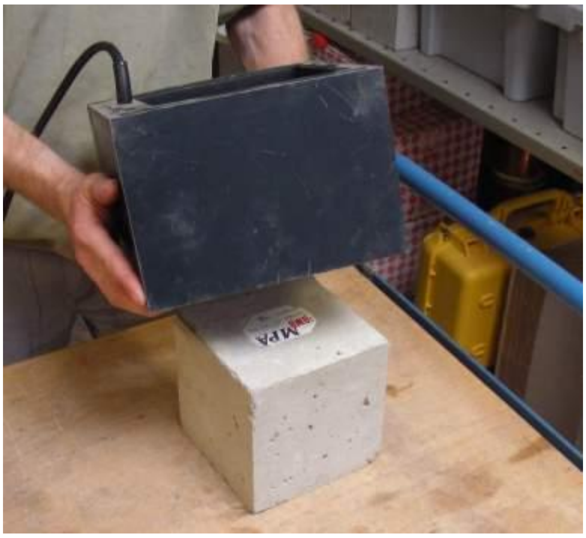

Fig. 5: Test cube

6. Fiber dosage measurement

Steel fibers are produced in many shapes and sizes. Due to different performance levels and requirements, the alloys used vary a lot. In order to determine the exact steel fiber dosage of a concrete sample, an initial calibration using calibration samples of the same steel fiber type is required.

Fig. 6 shows the calibration results of five different steel fiber types. For each steel fiber type, six different test cubes with steel fiber dosages from 10-60 kg/m³ were produced and calibrated. As in figure 6 displayed, for all types the induction voltage U_i is an almost linear function of the steel fiber dosage.

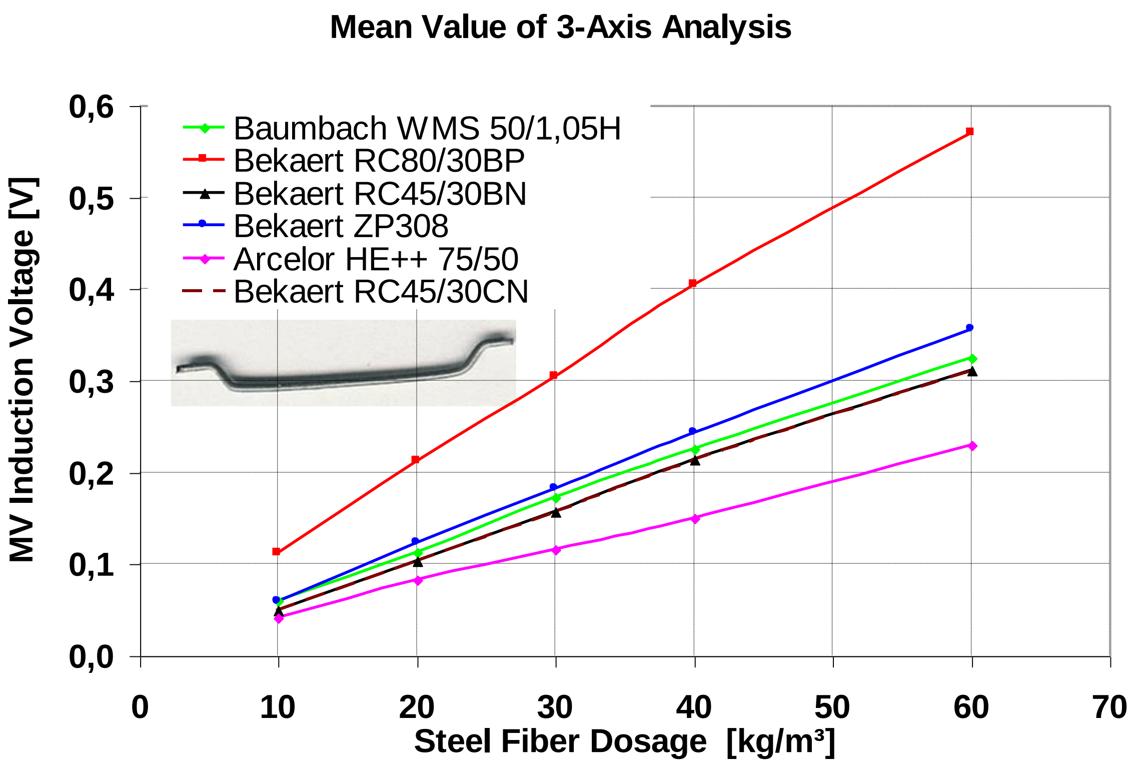

Fig. 6: Calibration diagrams of test cubes for six different steel fiber types

The coil-sensor can als be used to examine the steel fiber dosage in drilling cores. Here too, the induction voltage is measured in the three directions in space. The volume of a 15 cm long drilling core with a diameter of 15 cm is 21% lower than the volume of a 15 cm test cube. Thus, the measurement values have to be adjusted by a correction factor. Drilling cores longer than 15 cm must be shortened. For shorter drilling cores, a correction of the measurement results is necessary.

7. Steel fiber orientation

A steel fiber can be considered as a magnetizable rod with a preferred orientation. In a magnetic field, the rod is magnetized and tries to align tangential to the lines of the magnetic field. If all steel fibers are aligned tangential to the magnetic field, the induction voltage is at its maximum. If all steel fibers are in cross direction to the magnetic field, the induction voltage is at its minimum (fig. 7).

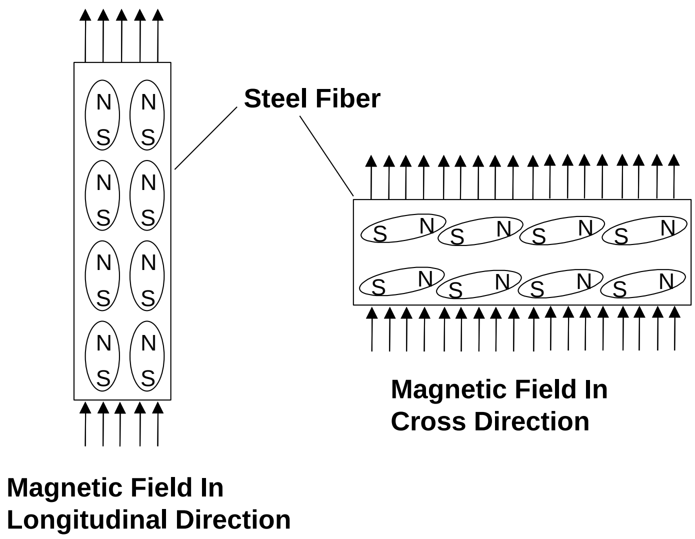

Fig. 7: Steel fibers in a magnetic field

In order to determine the relation of the induction voltage U_i to the angle between steel fibers and magnetic field, differents sets of 20 g steel fibers were attached on pieces of cardboard. The inclination of the piece of cardboard was increased in steps of 3° (fig. 8)

Fig. 8: Piece of cardboard with steel fibers

Fig. 9 shows the standardized induction voltage U_i in relation to the angle between steel fibers and magnetic field for two different types of steel fiber.

RC80/60BN is a low carbon, cold drawn wire fiber with hooked ends. The fiber is not coated. OL13/.20HC is a straight high carbon steel wire fiber without hooked ends. The fiber is brass coated and used for high-performance concrete.

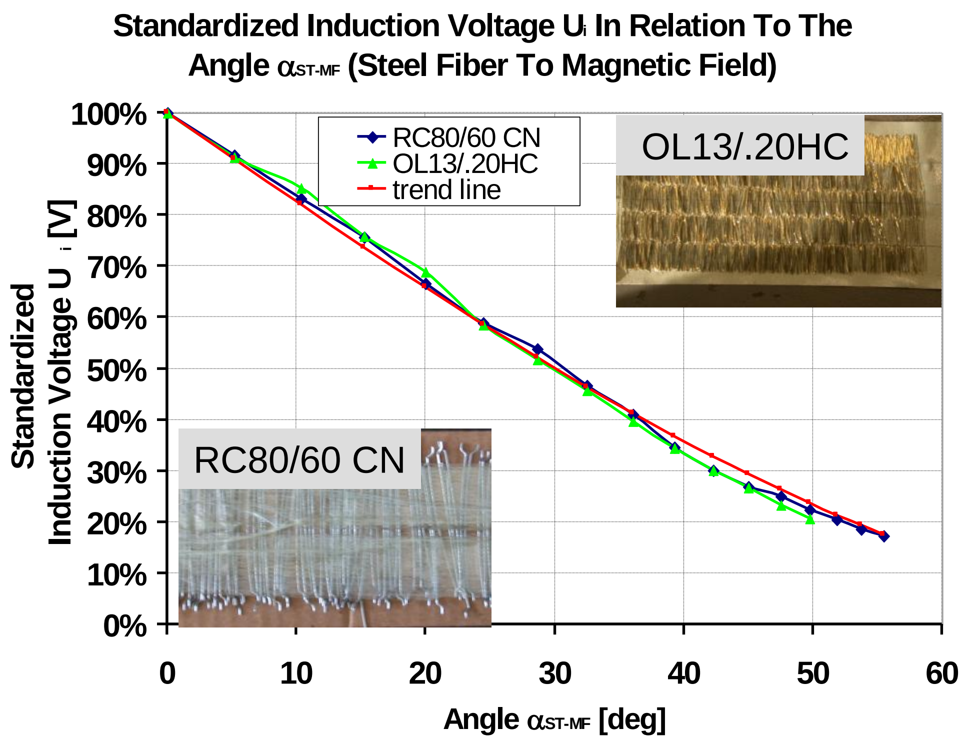

*Fig. 9:*Standardized induction voltage U_i in relation to the angle α_{ST-MF}

With increasing angle α_{ST-MF}, the induction voltage U_i decreases. Eq. 1 shows the relation of the induction voltage to the angle α_{ST-MF}.

$$U_i = U_{i\_MAX} \cdot (1 - \sin(\alpha)) \qquad \text{(Eq. 1)}$$

Fig. 10 shows the diagram of a 4 m long concrete member, made of steel fiber concrete. Four concrete bars (see fig. 10, labelled 1 - 4 , each bar of dimensions 72 x 12 x 12 cm) were cut out and divided in 6 cubes of 12 cm.

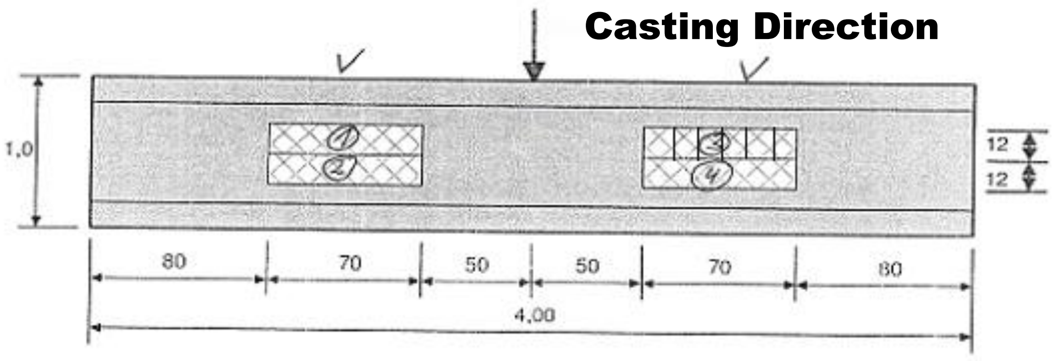

Fig. 10: Concrete Member

The cube were named 1.1 to 4.6, relating to the position they were taken from. The x-axis of each cube was defined as the casting direction of the concrete (see fig. 11).

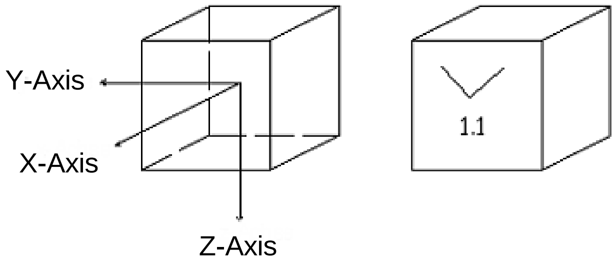

Fig. 11: Axes Definition

Table 1 shows the results of the six cubes taken from position no. 1. For all cubes, the induction voltage in direction of the x-axis is the least of all three directions. Without calibration samples, the fiber dosage of each cube is only measured relatively to other cubes.

The percentage of each single measurement indicates the orientation of fibers in the sample. A higher percentage of measurement shows that more fibers are orientated in that direction. Or in other words: The higher output value in a single direction corresponds with a higher amount of steel fibers pointing in that direction.

Table 1: Fiber orientation and relative steel fiber dosage of concrete test cubes

Percentage				
Sample	**x-Axis [%]**	**y-Axis [%]**	**z-Axis [%]**	**rel. fibre dosage [%]**
1.1	16,5	31,7	51,8	107,80%
1.2	13,1	47,6	39,2	105,70%
1.3	11,9	53,1	34,9	102,70%
1.4	11,9	64,7	23,4	93,50%
1.5	15,5	59,9	24,6	93,50%
1.6	14,8	56,1	29,1	94,50%

8. Temperature Dependence

Fig. 12 shows the influence of temperature on the measured fiber dosage of test cubes with a steel fiber dosage of 40 kg/m³. At lower temperatures the magnetic induction is lower than at higher temperatures. As a result, the measured fiber dosage is lower than it is in reality. If the measurement had to be performed on very cold samples, a temperature compensation is necessary.

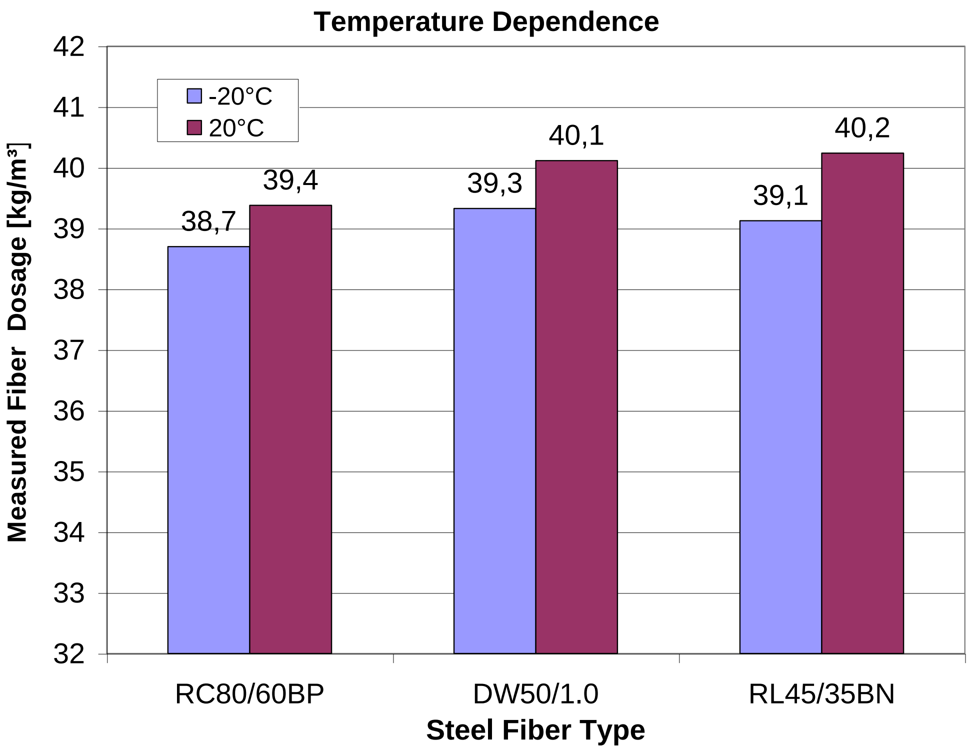

Fig. 12: Temperature dependence of measured fiber dosage using magnetic induction

9. Measurement device

The measurement device BSM100 (see fig. 13) was developed in a cooperation between the University of Braunschweig, Germany, and "Hertz Systemtechnik" in Delmenhorst, Germany, [3].

Calibration data of already calibrated steel fiber types, called "fiber profiles", are already stored in the "BSM100". New user-generated "fiber profiles" can be downloaded. The BSM100 works with 230V, 12V and an internal off-grid power supply, allowing continuous measurement directly on site and in the laboratory. A complete remote control from a PC or a subsequent download of the measurement data is possible.

Fig. 13: Measurement device BSM 100

10. Conclusions

In this project a new and advanced measurement device, using a coil sensor, was developed. It it possible to determine the steel fiber dosage and steel fiber orientation in concrete test cubes, fresh concrete samples and drilling cores. The robust sensor and measurement device is easy to handle and can be used in the laboratory and on site.

Previously calibrated fiber profiles already stored in the measurement device enable a real-time measurement of samples taken during production on site.

11. References

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