PAPER REF: 4011

VARIOUS CONTROL METHODS DEVELOPED FOR FIBRE-CONCRETE STRUCTURES

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ABSTRACT

Concrete can be modified by a number of admixtures that can considerably improve its mechanical properties. Low tensile strength of concrete can be increased by inserting metal wires into its structure that hold such tensile tensions to a certain extent. Designing and production of fibre-concrete with suitable properties are already a common practice. However, additional inspections have often proven that the distribution of wires is not optimal and therefore not each positive feature of fibre-concrete can be utilized, especially in constructional concrete applications.

Keywords: non-destructive testing, fibres, homogeneity, magnetic method, radiography

INTRODUCTION

A homogeneous structure of fibre-concrete is one of the most important factors to secure the reliability of such fibre-concrete structures. If the homogeneity of fibre-concrete is not observed, the material has different properties in various parts of the structure (for example, tensile strength), which can lead to the defects in the structure (generation and development of cracks). The relevant lower reliability of the structure which is caused by unequal distribution of fibres (wires) in concrete volume can lead to damage of the property as well as the safety and the human lives can be jeopardized. Hence it is necessary to secure the effective control of the fibre-concrete homogeneity in ready support fibre-concrete structures.

The prerequisite of the homogeneity of fibre-concrete used in support structures is to observe the principles of fibre-concrete technology. This is based on designing the proper fibre-concrete composition, where so-called aeration of aggregate mixture with fibres must be taken into account for a higher density of fibres, and furthermore, the correct procedure of production technology of fresh fibre-concrete production and the determination of the proper consolidation of concrete during concrete works of fibre-concrete structure must be considered. For the detailed description of the individual phases of fibre-concrete technology, see for example (Barr, 1990).

POSSIBLE METHODS TO CONTROL THE HOMOGENEITY OF FIBRE CONCRETE

It is not difficult to assess the fibre-concrete homogeneity in fresh samples taken during concrete work. However, more complicated task is to find information about the fibre-concrete homogeneity built in the support structure. Additionally to borehole sampling and their analyses, it is necessary to find out other methods - the tests which would give the reliable information about the material homogeneity. Basically, two physical properties by which fibre reinforcement differs from the ambient materials can be used:

a) higher fibre density (ρ= 7850 kg/m^3), compared to concrete (ρ = 2300 kg/m^3),
b) magnetic properties of soft steel fibre (permeability μ_r >> 1 in steel, μ_r ~1 in concrete).

The former property, i.e. density, can be determined by radiography while the latter property, i.e. permeability, can be estimated by magnetic and electromagnetic methods.

BASIC SET OF FIBRE-CONCRETE CONTROL BLOCKS

Three sets of samples with different fibre concentrations, i.e. 0.0 %, 0.5 %, 0.75 %, 1.0 %, 1.25 % and 1.5 % were prepared for calibrations and testing of the new methods for fibre concentration measurements in concrete. Three kinds of fibres were applied: TRI-TREG (60 mm long), DRAMIX (50 mm long) and FIBREX (25 mm long). The samples were made in the moulds with dimensions of 300 x 300 x 150 mm. Such dimensions were selected so that the samples could be easily manipulated, and at the same time, they were big enough to eliminate the "marginal" effects during the processing of fibre-concrete. All principles for fibre-concrete production were observed during concrete production.
Consecutively, the samples were cut by a diamond disc and divided into five parts (Fig.1) which were used for the calibration of individual methods.

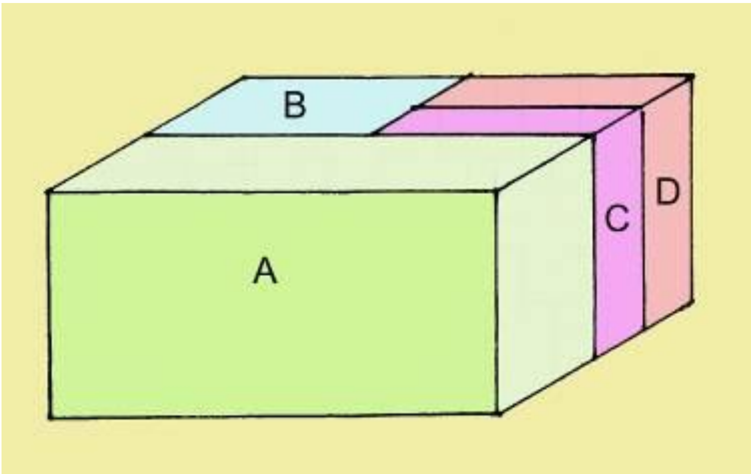

Fig. 1 The scheme of the calibration fibre-concrete sample

X-RAY TESTING OF FIBRE CONCRETE

The X-ray testing method is a progressive method which is based on X-ray pass through the mass and a detection of density differences in non-homogeneities and its recording on a suitable medium. The fibre-concrete testing can be used under certain conditions. Because this is the imaging method, the fibre-concrete plates which are accessible from both sides can be used. By means of radiography, the prevailing direction of fibres in the controlled area can be determined.
An EcoRay HF 1040, portable X-ray unit, which with its small-scale dimensions and low weight (12.5 kg) is intended for field radiographic testing operation (Fig. 2). The AeroDR

convertor (Minolta-Konica) was used for detection, and it can directly digitize an X-ray image and transferred it with wireless connection to the next processing to a PC (Fig. 3).

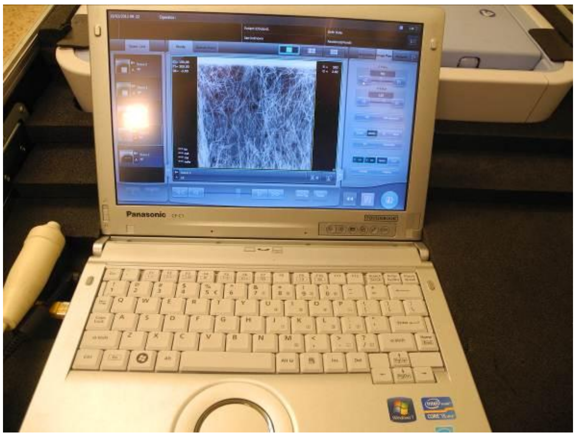

Fig. 2 X-ray machine EcoRay HF 1040 *Fig. 3 Digital recording to PC*

The calibration samples with TRI-TREG fibres (60 mm long) and with concentrations of 0.5%, 0.75%, 1% and 1.25% (Fig. 4), dimensions of 150 x 150 x 70 mm were prepared for the first measurements. A focal distance of 700 mm was selected for radiography, and the parameters U= 75 kV and t= 63 mAs (Fig. 5) were set in the X-ray unit. The samples were successively exposed to radiation, and the radiograms were mathematically processed

Fig. 4 Calibration samples of steel fiber *Fig. 5 Schematic radiography samples*

by means of the MATLAB Image Processing Toolbox (an image processing and analysing software) and NIS Elements. The line objects (fibres) were detected in each analysed image by the image processing methods and by mathematical morphology, and the images were converted by "thresholding" into a binary form (the black objects of fibres on the light background), and then the central axes of the fibres imaged as the lines with a thickness of 1 pixel were created. Only the lines which were directed in the degrees of 0, 22.5, 45, 67.5, 90, 112.5, 135 and 157.5 were gradually separated in the image with the central axes. The total line length was measured in each direction. The results of determining the prevailing fibre direction in concrete were shown in the rose diagrams. The digitized radiograms and the corresponding rose diagrams are shown in Figs. 6 and 9 from which the prevailing fibre direction can be determined.

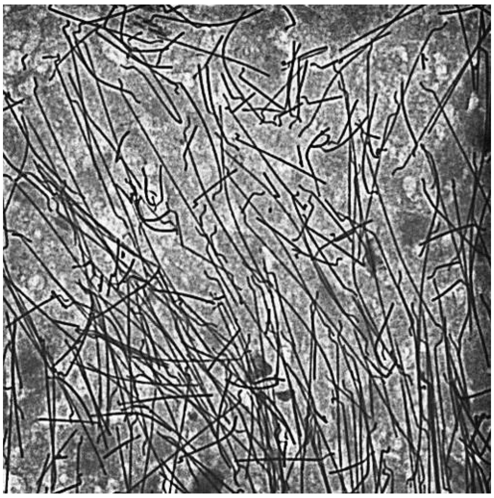

Fig. 6 a Sample B-1-c (0.5 %)

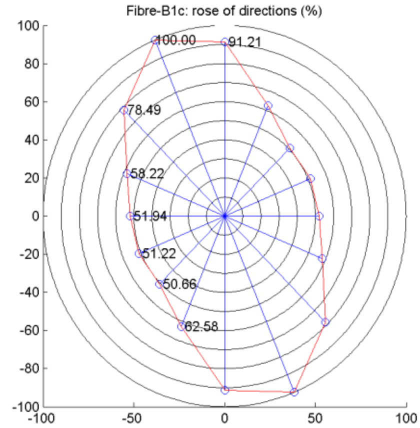

Fig. 6 b Rose diagram B-1-c

Fig. 7 a Sample B-2-c (0.75%)

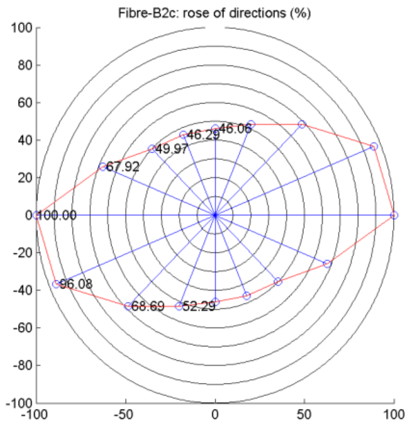

Fig. 7 b Rose diagram B-2-c

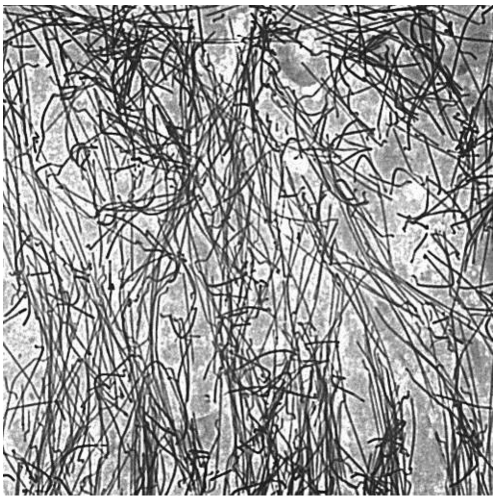

Fig. 8 a Sample B-3-c (1.0%)

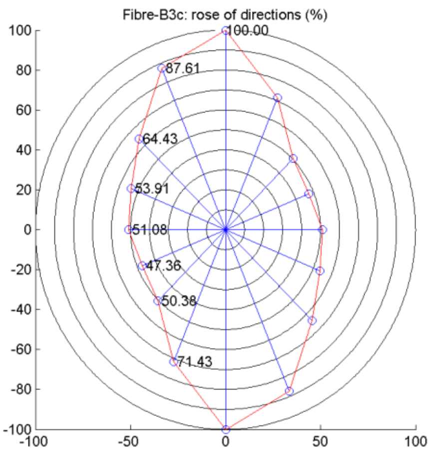

Fig. 8 b Rose diagram B-3-c

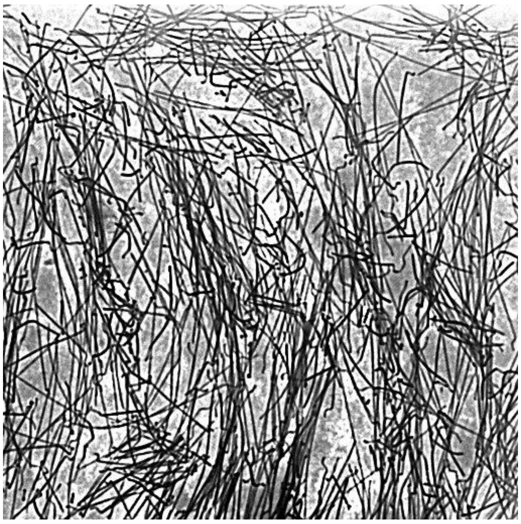

Fig. 9 a Sample B-4-c (1.25%)

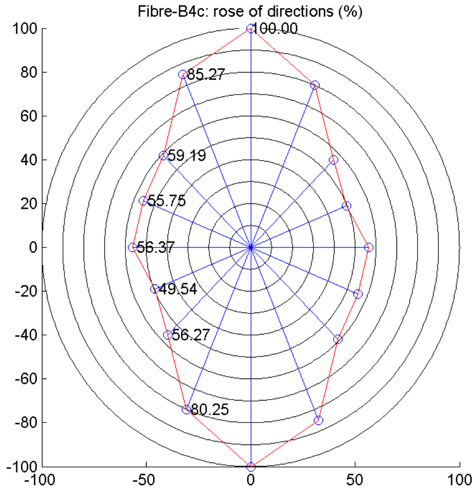

Fig. 9 b Rose diagram B-4-c

Based on the radiography test results, it can be assumed that the optimized thickness for testing the fibre-concrete plates by exposing to radiation is 50 to 80 mm, and however, this thickness depends, to a certain extent, on the fibre concentrations in a fibre-concrete plate.

A certain disadvantage of radiography is that the „three-dimensional“ sample is recorded on a „two-dimensional“ recording medium. Hence the reinforcement fibres which are approximately parallel with the irradiation direction are deteriorated, i.e. they are shorter in the image. This affects the attempts to estimate the number of fibres in the tested sample based on the radiograms.

In conclusion, it can be said that the radiographic fibre-concrete testing method, related to the image analysis, is a very precise method which can determine the fibre distribution quality in the sample. However, its disadvantage is that the samples must be specially adapted so that the plates are suitable for irradiation. It is evident that this method can be used advantageously for verification of the calibration samples used for the other fibre-concrete testing methods.

This method also proved that, even in the calibration samples produced very carefully, a tendency of fibres for the horizontal orientation which was probably caused by vibration during the concrete mixture processing.

It is evident that this method was advantageously used even for the non-destructive tests of fibre direction in a self-compacting fibre-concrete which was described, of course by a destructive method, in the Joaquim Barros‘s paper, called „Assessment of Fibre Orientation and Distribution in Steel Fibre Reinforced Self-Compacting concrete Panels“ (Barros, 2012).

The disadvantage of the radiographic methods to quantify the number of fibres in fibre-concrete has led to a development of the „magnetic method“ based on a different permeability in steel and concrete.

MAGNETIC TESTING OF FIBRE - CONCRETE

Fibres contained in fibre-concrete that were produced from common steel had high permeability $\mu_r >> 1$ compared to concrete that had very low permeability $\mu_r \sim 1$. Fibres distributed in concrete increased its permeability which was to be correlated with their concentration.
The next project solution was focused on the determination of magnetic properties of fibre concrete during utilization of electromagnetic and magnetic properties of fibre-concrete.
Several alternative methods have been presented in the literature: namely (Van Damme et al., 2004) estimates the effective material permittivity employing a coaxial probe together with microwave reflectometry techniques, (Ozyurt et al., 2006) comes from the AC-impedance spectroscopy, (Lataste et al., 2008) performs special low-frequency electrical resistance measurements and (Faifer et al., 2009) develops a method based on impedance-over-frequency measurements, employing certain two-electrode probe, supported by the numerical fast Fourier transform. Recently (Faifer et al., 2011) and (Wichmann et al., 2012) try to exploit the ferromagnetic behaviour of metal particles to evaluate their volume fraction; the deviation of measurement values then gives basic information to the required homogeneity and isotropy. However, the completely non-destructive measurements cannot handle massive structures; then also another type of the low-invasive approach is needed, as discussed lower.

Depth permanent magnetic probe (PeMaSo)

The above-mentioned methods were intended for testing of the surface fibre-concrete layers while their depth range was not high. However, in practical terms, the control in the whole structural volume was required. Based on the knowledge acquired, the development of the depth magnetic probe was started with the aim of measuring in pre-drilled holes in the structure. The diameter of holes was 25 mm. The method was based on the properties of permanent magnets which formed magnetic field characterized by magnetic lines of force. It was evident that if the permanent magnet was placed into the environment with ferromagnetic material (fibres), the magnetic field of permanent magnets was affected in its shape. If the field was reliably measured, the correlation could be found between an increase of fibre concentrations in fibre concrete and a change of magnetic field strength.

a**) Developmental magnetic probe with permanent magnets (PeMaSo-01)**

To verify the tasks described above, the test probe (called PeMaSo-01) was manufactured which was made of aluminium tube with an external diameter of 25 mm and into which the cylindrical permanent magnets with a diameter of 22 mm and a length of 10 mm was inserted. In a selected distance along the cylinder axis, the Hall probe which measured magnetic field inside the probe (aluminium tubes) was installed. The distance of the Hall probe from the magnet surface was adjustable (Fig. 10). A number of measurements proved that the optimized quantity of permanent magnets was four (4), each with a length of 10 mm, and each behind other. It was also proved during the measurement with the Hall probe that the sensitivity increased with an increasing distance of the Hall probe from the surface, however the magnetic field strength measured with the Gauss/Teslameter was reduced. The distance of 50 mm of the Hall probe from the magnet surface seemed as most as suitable. Four (4) samples, i.e. the cubicles with drilled bores (Fig. 11), demonstrated very good correlation (Fig. 12) between a reduction of magnetic field strength and increasing fibre concentrations in the samples.

Fig. 10 PeMaSo-01 developmental probe

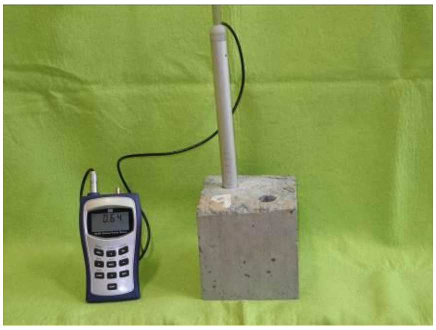

Fig. 11 Measurement by a probe in the calibration sample

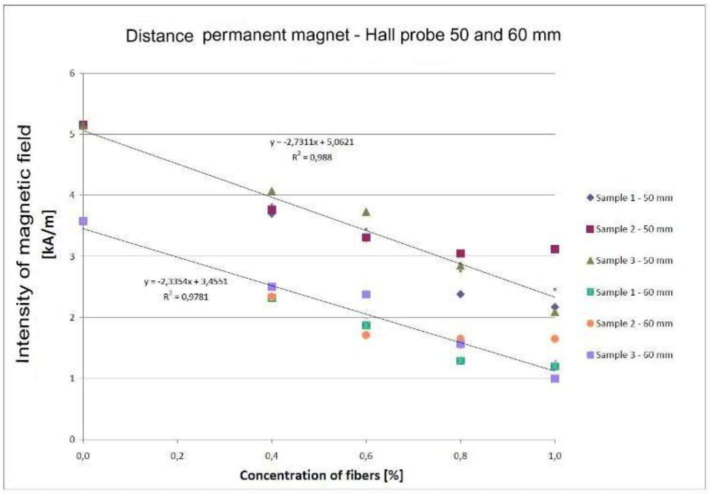

Fig. 12 Correlation between magnetic field strength and increasing concentrations of fibres in samples

b) Prototype of depth permanent magnetic probe PeMaSo-02

The PeMaSo-01 developmental probe was used for the verification of operations and the selection of parameters. However, it was not possible to measure in a depth of fibre-concrete structure. For this purpose, the PeMaSo-02 probe was designed in which the parameters were fixed for the optimized measurement (Fig. 13).

Fig. 13 PeMaSo-02 depth probe prototype

A certain fluctuation of the values was observed during the measurements with the probe in steps of 10 mm in the calibration sample with a length of 300 mm. The fluctuation proved that even for the constant fibre concentration in the calibration sample the measurements could be affected by the prevailing direction of dispersed fibres. Hence, the final measurement results had to be determined as the arithmetic average from the partial measurements (Fig. 14).

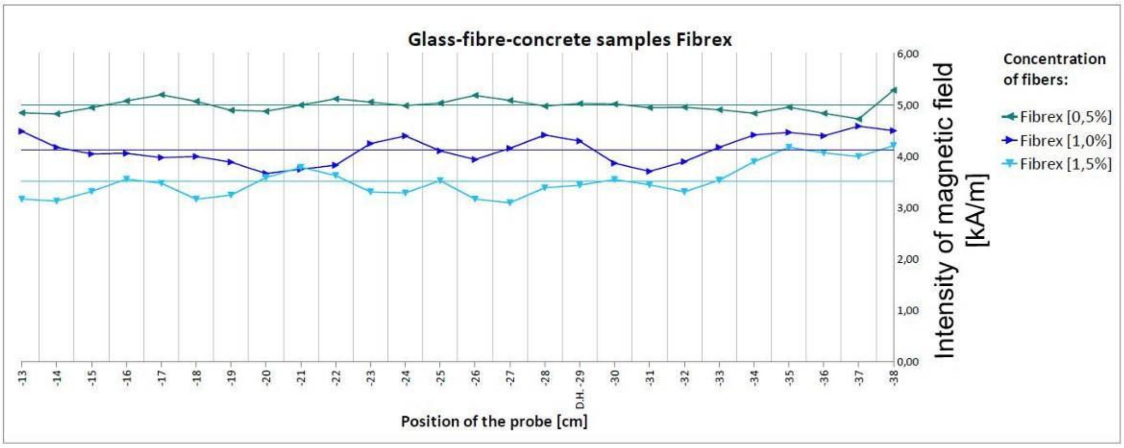

Fig. 14 Continuous measurement by PeMaSo-02 probe in a 300 mm sample

RESULTS AND CONCLUSIONS

The first phase of the research work referred to the control methods for fibre-concrete homogeneity testing was focused on the production of credible calibration samples with guaranteed fibre concentrations and also on the methods which could determine the fibre concentrations in hardened surface. A radiographical method (Hobst, 2011) was also successfully tested, which completed with the image analysis method, could determine the fibre distribution (direction) in the samples.

In term of fast and operative fibre concentration evaluation in fibre-concrete structures, the next research was focused on magnetic methods (Vala, 2012). The measuring instruments, based on the similar principle as magnetic indicators of reinforcement, were tested, and also new permanent magnets which had significantly deteriorated their magnetic field due to the presence of fibres were tested. The majority of the tested methods demonstrated the positive results, however, the methods were partly limited due to their physical measurement principles. The very perspective method seemed to be the method based on the measurements of deformations of the magnetic field generated by permanent magnets in the "depth probe" which was usually placed into the pre-drilled micro-holes in fibre-concrete structure. Its development and the results showed the properties for which the "depth probe" can be submitted as the "utility sample" in the future, and moreover, the new standard NDT tests for the monitoring of hardened fibre-concrete homogeneity can be proposed.

ACKNOWLEDGMENTS

The financial support of the FAST/ÚSI-S-12-1 research work is greatly acknowledged.
Acknowledgements for borrowing EcoRay HF1040 by company Smira-Print.

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