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Experimental testing of the electromagnetic coil – determining the range of electromagnetic coil

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Abstract The principle of steel fibre reinforced concrete structures is a uniform distribution of steel fibers in the given volume (structure or structural element), which, however, is not always possible to guarantee in the production. This is closely related to a problem of performing diagnosis of the existing steel fibre reinforced concrete structures. Despite the fact that this material is not unknown, in the standards regulating quality control of the uniformity of fibre distribution, the assessment of distribution uniformity is still based on a destructive testing method. The paper describes a partial experiment which consisted in testing a proposed measuring device and in determining the depth of electromagnetic field range in the test specimens.

1. Introduction

In order to improve certain physical and mechanical properties of fresh concrete, additives and admixtures are added to it [1]. Steel fibres can also be regarded as a certain type of additive, giving rise to a building material called steel fibre reinforced concrete. Thanks to the specific properties obtained precisely by adding steel fibres of various sizes and shapes, steel fibre reinforced concrete can be used for achieving other required parameters of concrete elements with a view to their use in the structure [2]. Fibres improve resistance of concrete against mechanical stress, thermal stress and, above all, they improve the tensile resistance of concrete, even after the occurrence of cracks, when its ductility comes into play. These improvements of physical and mechanical properties of steel fibre reinforced concrete are highly welcome, especially because concrete is characteristic of brittle failure and the subsequent loss of its load-bearing capacity, which occurs immediately as a result of the failure [3-4]. Composite materials require much attention not only during designing the technological process of their production, but also during the production alone and during their subsequent testing. This is given by the fact that their properties are determined not only by the properties of individual components, but also by the proportions of their amounts per a unit of volume. Also important is the resulting homogeneity of fibre concrete, on which the improvement of its properties depends. Physical and mechanical properties of steel fibre reinforced concrete can change depending on the distribution and orientation of fibres [5-6].

It is problematic to perform a diagnosis of steel fibre reinforced concrete structures. It is not yet possible to verify compliance with the technological procedure for the production and execution of construction works by means of non-destructive methods, which are highly desired by the investors. One of their major advantages is the repeatability of tests performed and mainly their non-destructive result. Although the destructive testing methods performed on the extracted drill cores offer a much more precise interpretation of the measured values, many research institutions in Europe focus on the development of new NDT methods for steel fibre reinforced concrete testing.

Methods on the principle of which it is possible to assess the concentration of steel fibres in both fresh and hardened steel fibre reinforced concrete, already exist, however, assessing the orientation of fibres is considerably more difficult. Experiments show that it would be possible to check concentration and distribution of fibres on the basis of the ferromagnetic properties of steel fibers in steel fibre reinforced concrete non-destructively [7]. Diagnosis of steel fibre reinforced concrete structures is common, and the construction practice would highly welcome the possibility to use a measuring device proposed for checking the homogeneity of steel fibre reinforced concrete. The fact that design regulations should also include a method of non-destructive testing of the homogeneity of steel fibre reinforced concrete is mentioned also in [8]. Of course, development of every new method and methodology is time consuming and the final results not always confirm their applicability. On the basis of the requirements of construction practice, the authors participated in the development of a new non-destructive method of testing – proposing a new measuring device and methodology of testing steel fibre reinforced concrete. This device works on the principle of measuring physical quantities describing the electromagnetic field arisen by connecting an electromagnetic coil to the electric circuit. The principle of the measurement consists in measuring the inductance, during which the electromagnetic coil with a ferrite core is attached to the surface of concrete and gives rise to an alternating electromagnetic field. Presence of steel fibers increases the magnetic permeability of the composite material compared to a mixture without fibres, which implies an increase in the measured induction during the motion of the electromagnetic coil. Rotating the coil about its axis figure 1 and changing its position in the grid along the surface of the tested specimen thus allows to determine, from the measured values, the prevailing orientation of fibres [9].

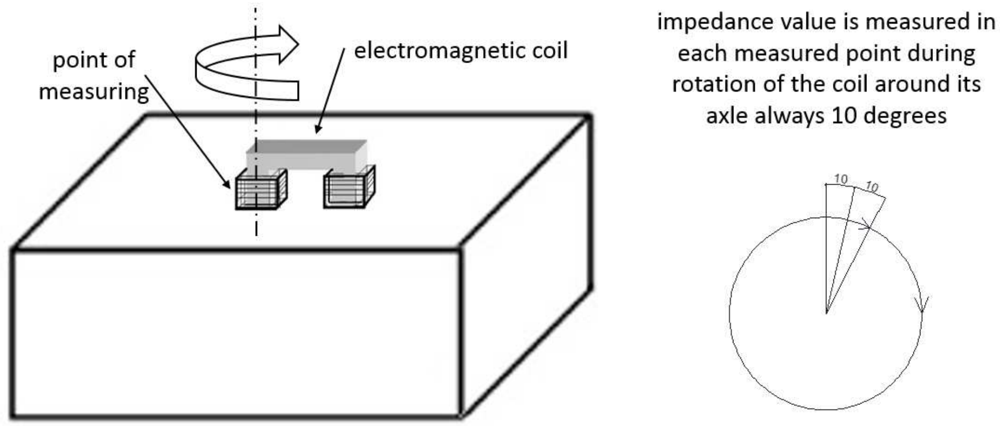

Figure 1. Methodology of testing the specimen.

Methods that are currently used are based on the evaluation of the electrical impedance of the tested specimen where the parameter monitored is the electrical impedance module. The prerequisite for the measurement proper is a dependence between the value of impedance and the concentration of fibres, which was demonstrated in the laboratory tests. The performed experiments showed that it is possible to monitor the concentration and distribution of fibres non-destructively using the electrical and ferromagnetic properties of steel fibres as a composite filler in the steel fibre reinforced concrete. The use of a suitable methodology of measurement and of the frequency band near the resonance of the sensor-specimen configuration allows for a more precise derivation and evaluation of the composition of the monitored composite component. The non-destructive methods used up to now utilize the properties of the electromagnetic field for a monitoring of fibre distribution in the tested composite. The properties of composite steel fibers are evaluated on the basis of the principle of electrical impedance in the area of the tested specimen. Details of the fields and other aspects are illustrated e.g. in figure 2.

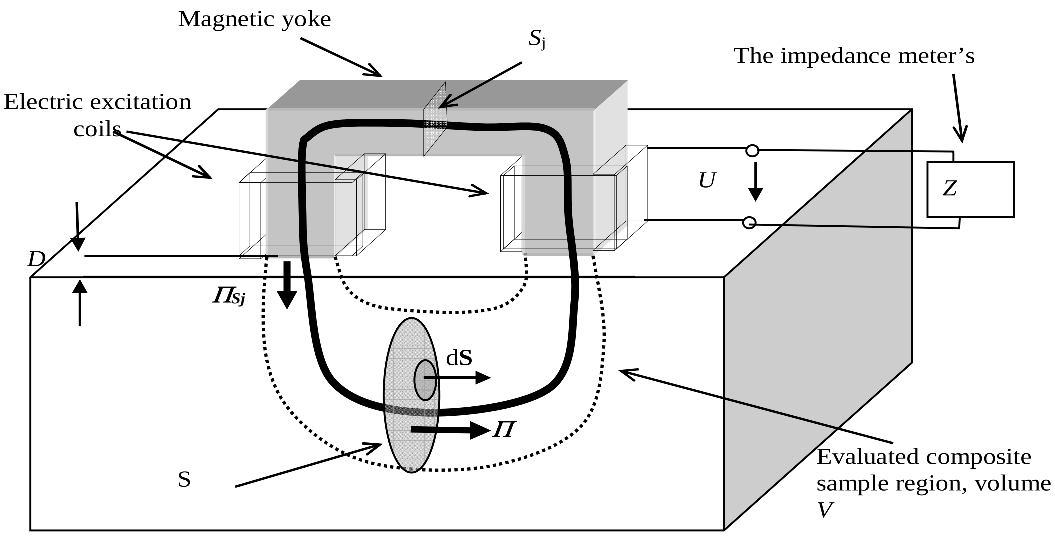

Figure 2. A scheme of the impedance-based NDT method: the evaluation of the tested sample parameters.

The hitherto experiments lead to determining the most suitable setting of the selected parameters, which is described in detail in. The first partial experiment determined the range of the electromagnetic field in the tested environment, and thus the maximum depth, in which it is possible to determine the steel fibre concentration and distribution uniformity from the data measured. The article describes results of the first experiments performed according to the newly proposed methodology and with the newly developed measuring device with the aim to determine the maximum range depth for the given setting [10].

2. Experiment

The experiment was performed using the methodology described in [9], where an electromagnetic coil with a ferrite core is attached to the surface of the test specimen. An electromagnetic field arises in the given volume, and by measuring impedance and power dissipation it is possible to assess especially the uniformity of steel fiber distribution in the controlled area and also in the given depth. When testing the new device, the initial effort was aimed at proving the range of the arising electromagnetic field and thus at confirming the correctness of the setting. 5 different resonance frequencies were selected assuming the differentiated sensitivity of the measurement and mainly the maximum depth of the electromagnetic field range [9-10]. Testing the range of the electromagnetic coil was performed using polystyrene slabs between which slabs with steel fibres were put at regular distances, always after 1 cm, see Fig 3. At the same time, it was ensured that no magnetically conductive material was found around the measuring device during measurements. This guaranteed that the electromagnetic coil reacts only to steel fibres placed on the polystyrene specimen.

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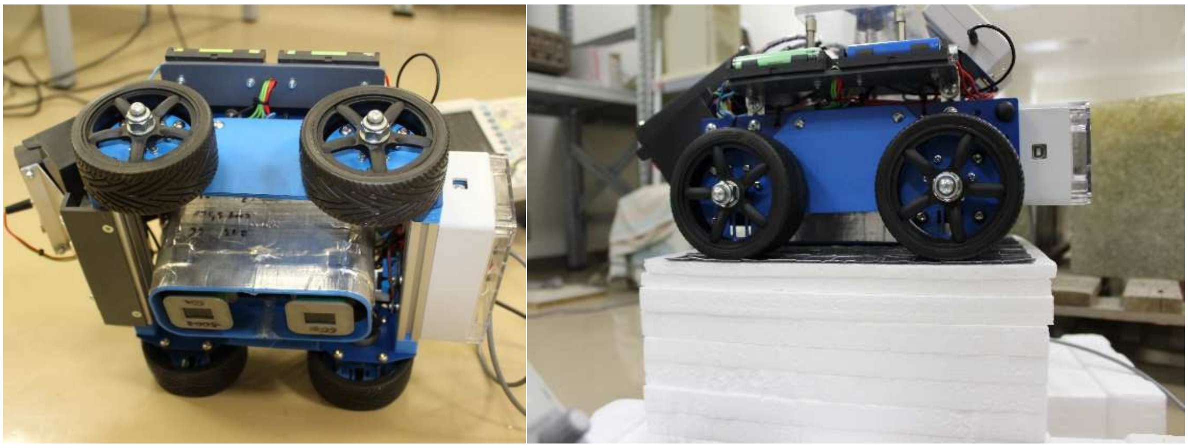

Figure 3. a) Proposed measuring device - electromagnetic coil situated underneath the device (left) b) Calibration of the electromagnetic field range (right).

3. Results and discussion

The measurement was performed for all the 5 settings of resonance frequencies (327 kHz, 145 kHz, 50,12 kHz, 21,9 kHz, 3,45 kHz), and the results achieved confirmed the assumption of varying ranges with the given settings. At the same time, uniform distribution of fibres in the selected area was confirmed, which can be observed in the chart of evaluated values in Fig. 4. The achieved results of testing the new measuring device are more than satisfactory. The following figure shows charts indicating the range of electromagnetic coil for the resonance frequency setting of 327 kHz. The measured values, which are compared, are power dissipation, impedance – angle and phase. The graphic representation indicates that at a steel fibre plate distance of 5 cm from the electromagnetic coil, none of the measured values changes, i.e. the maximum range of the electromagnetic field with the given setting is precisely 5 cm. The assessment was performed for all 5 resonance frequencies.

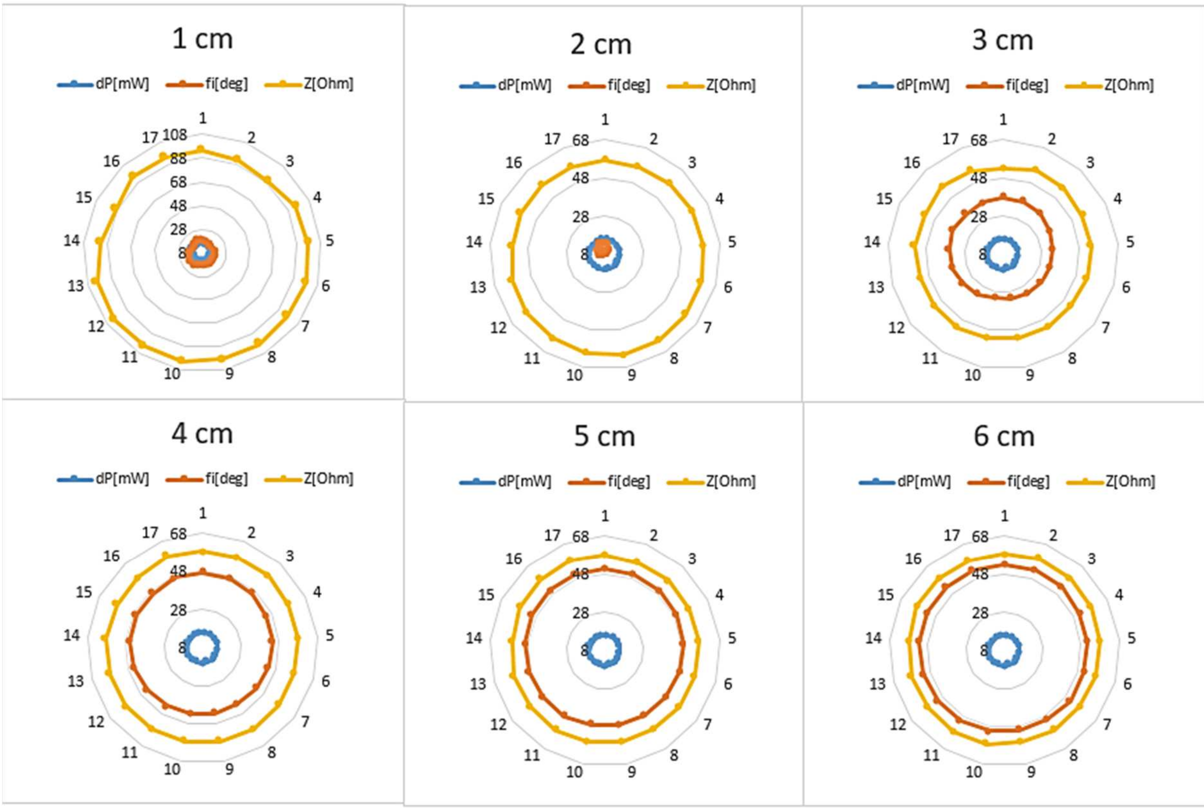

Figure 4. Graphical evaluation of the measured values – comparison of changes in the measured values depending on the distance of steel fibres from the surface of the electromagnetic coil.

4. Conclusion

By performing the experimental measurements in the laboratory on test specimens, it was possible to derive and prove the basic principles of the NDT method and methodology. The method is based on the physical principles of evaluation of the electrical impedance components of the magnetic circuit linked to the tested composite specimen, and the preliminary test results suggest its successful inclusion among the applicable NDT diagnostic methods used outside the laboratory. The potential of the proposed device is indisputable. The proposed methodology can be applied for a non-destructive diagnosis of a composite material either with a ferromagnetic addition, or with an electrically conductive addition with irregular shape of the composite component. The results of the first test experiments demonstrated the accuracy of the initial assumptions, and simultaneously, on their basis, it is possible to extend the experiment and determine validations of the methodology. The measurement results obtained from the first experiments show that with an appropriately selected setting, it is possible to perform measurements of steel fibre reinforced concrete to a set depth – for a frequency of 327kHz, to a depth of 5 cm. The hitherto positive measurement results proved a great potential of the proposed methodology, and after performing further laboratory tests, the proposed measuring device could be used in the diagnosis of steel fibre reinforced concrete structures.

Acknowledgement

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