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SURVEILLANCE OF STEEL FIBRE REINFORCED CONCRETE SLABS MEASURED WITH AN OPEN-ENDED COAXIAL PROBE

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Abstract − Conventional concrete structures are nowadays being substituted by steel fibre reinforced concrete (SFRC) in some structural applications. Then, fibre dosage and distribution is a keyword for ensuring quality control of structures. The present work analyses the possibility of an Open Ended Coaxial Probe as an element for ensuring the quality of a concrete slices.

Keywords: fibre reinforced concrete, open ended transmission line sensor

1. INTRODUCTION

Nowadays, more structures and elements of concrete are manufactured filled with fibres of steel [1], [2], [3], [4], [5]. Apart from saving time in rebar manipulation, the fibres may prevent initial fissures. In addition, since the fibres are added to the solid phase before the mixture, thinner structures can be achieved.

The advantage of adding fibres to the solid phase and pouring with has a disadvantage compared with traditional rebar placing: The process has to ensure the fibre distribution homogeneity [6]. For a good quality control of this distribution inside bulk material or concrete, novel measures techniques have to be developed in order to check if fibres have been distributed properly inside it.

One candidate to measure technique for quality control comes from the telecommunication world. An electromagnetic wave propagates in a transmission line like a regular coaxial cable. If this transmission line suddenly ends in an open circuit, the wave reflects. This reflected wave is function of the material in contact with the open circuit end of the transmission line. The analysis of this reflected wave gives information about the material in contact with. In the past, this strategy was successfully applied to biological material [7]. Then, the open end of the coaxial transmission line became a sensor.

The Open-Ended Coaxial probe as a sensor for fibre detection can be found in the literature [8]. Van Damme's and co-workers correlated the sensor response to fibre dosage but they, neither other authors in the past, do not deal with penetration limits of the sensor. As the sensitivity of the method is function of the depth, fibres placed near the surface have higher response than others. The theoretical sensitivity limits of penetrating may be found from [9].

The aim of this work is to validate an Open Ended Coaxial Probe sensor for quality surveillance of slim structures of concrete reinforced with fibres, in order to measure the homogeneity in the distribution of fibre dosage.

2. MATERIAL AND METHODS

2.1. Sensor design

The Open Ended Coaxial Probe is a sensor widely used to measure permittivity variation in various applications. Each sensor has been usually designed ad-hoc choosing the dimensions of the inner and outer coaxial as a function of the desired cut-off frequency. However, this process is costly and sometimes makes it difficult to achieve perfect adaptation between cables and sensor. In this work, the sensor was made using commercial products, which makes the sensor possible to be replicated with industrial quality. This is essential if an array of sensors with identical characteristics is needed.

The sensor was made using a CELLFLEX LCF 158-50 JA cable, provided by the company RFS. It was cut using a saw, filed and assembled to its N-connector. A 1,4 kg load was put over the sensor in order to normalize the force between the sensor and the sample. A conductive mesh was soldered to the edges of the sensor to make a smooth transition and ensure total contact with the sample.

Fig. 1. OECTL Sensor.

2.2. Measurement instruments

Measurements from 200 MHz to 2 GHz were performed using a Vector Network Analyser (VNA) HP8753C. Data was transferred to a PC via GPIB, using a LabView driver, which measured 801 points per sample in linear sweep, with a power of 0 dBm. s_{11} parameter was measured for each sample. Complete setup with sensor, sample and VNA is showed in Fig 2.

Fig. 2. Experimental setup.

2.3. Sample preparation

All the tests were performed on a 600×150×20 mm mortar slice. The sample were produced using Ordinary Portland Cement and calcareous sand, passed through a 5 mm sieve, with a sand/cement ratio of 3,0 and a water/cement ratio of 0,50. No additives were used. Sample preparation included a first pouring of 10 mm of mortar on a box. The fibres were randomly placed in four areas of 150x150 mm, containing 0, 15, 30 and 45 kg/m^3 of fibres successively as seen in Fig 3. After pouring the fibres, a final 1 cm thick of fresh mortar was placed on. After curing, the sample was placed over two wooden stands, in order to avoid interferences due to metallic objects.

Fig. 3. 600x150x20 mm sample containing each 15x15 cm area different fibre dosages.

3. RESULTS AND DISCUSSION

Slice surface was divided in 45 points equally distributed on its surface. Every point was measured with the sensor so nine measurements correspond to each fibre content.

In an industrial application, calibration of a VNA can be cumbersome if it is not possible to get a well known open-, short- and load-references. Then, measures without calibration, if possible, are preferable. Usually, an open-reference is not necessary if sensor has a gap big enough to any disturbance object. In addition, gating allows removing any reflection different to one of interest (due to cable connexions and transitions).

Fig. 4 shows the reflection coefficient moduli average of nine measurements on the surface of each dosage versus frequency. Reflection coefficient moduli are related to how the wave attenuates in its way inside the surface of the mortar slice. Time-gating techniques were applied to raw data. In addition, Fig. 4 also shows few different results respect to frequency.

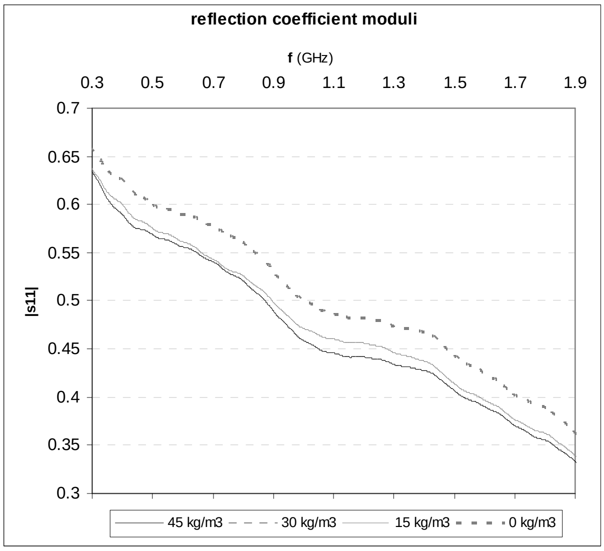

Fig. 4. Reflection coefficient moduli of the averaged measurements of different fibre content dosages.

Fig. 5 shows the reflection coefficient moduli only at 1 GHz. Although reflection coefficient is function of fibre dosage, a saturation effect appears at relative low dosage (45 kg/m^3). One additional characteristic shown in Fig. 5 is the slightly positive correlation between dispersion of measurements and fibre dosage. It is easy to figure out that as fibre density increases, sensor may detect or not a single fibre nearby. Then, it increases its dispersion. This Fig. 5 also demonstrates that in medium of high dosage fibre content, spatial averaging is necessary in order to obtain representative data.

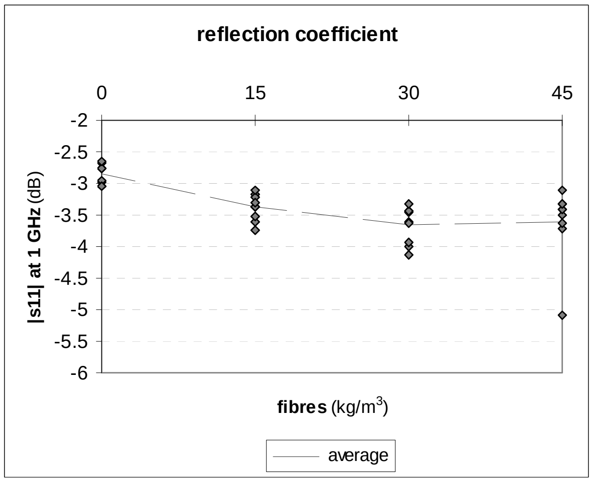

Fig. 5. Reflection coefficient moduli at 1 GHz of the single and averaged measurements of different fibre content dosages.

As reflection coefficient is a vector measurement, Fig. 6 shows phase results, from a frecuencial sweep between 0,2 and 2 GHz. Phase results are related to the speed of electromagnetic waves in the medium. If the exact path of the wave at the end of the transmission line was known, results could be translated to dielectric constant values. However, Fig. 6 shows phase results related to open circuit measurement obtained as a simple calibration procedure.

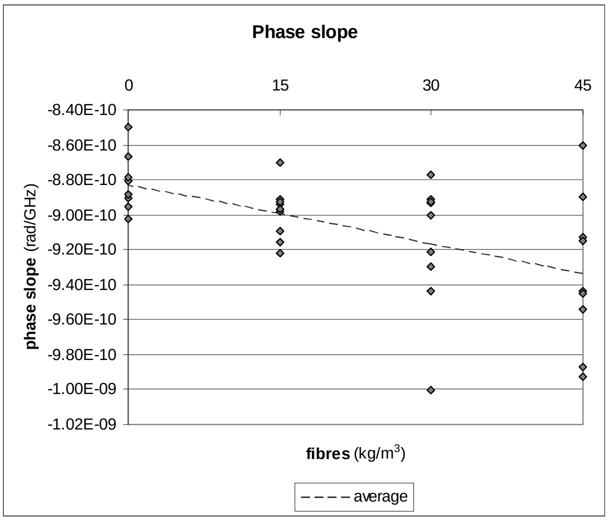

Fig. 6. Phase slope of the single measurements of different fibre content dosages.

Saturation effect, which appeared in moduli results, is not observed in the phase results. Reflection coefficient moduli is probably very sensitive to local conditions and contact among fibres, mortar bulk and gap between sensor position and sample surface. Phase results are more robust to this condition.

4. CONCLUSIONS

Fibre reinforced concrete need additional quality control measurements in order to ensure homogeneity in fibre distribution. Measurements with an Open-Ended Coaxial probe were performed leading to a good correlation between fibre content and phase differences in reflection coefficient. Results of the moduli showed saturation after the medium range of dosages, so it is not so suitable for industrial applications. This technique is only suitable for concrete slices due to its own limitations on the penetration depth of the sensing electromagnetic waves.

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