# Carbon-Based Composites Enable Monitoring of Internal States in Concrete Structures

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***Abstract*****—**Regarding previous research studies it was concluded that thin-walled fiber-cement composites are able to conduct electric current under specific conditions. This property is ensured by using of various kinds of carbon materials. Though carbon fibers are less conductive than metal fibers, composites with carbon fibers were evaluated as better current conductors than the composites with metal fibers. The level of electric conductivity is monitored by the means of impedance measurement of designed samples. These composites could be used for a range of applications such as heating of trafficable surfaces or shielding of electro-magnetic fields.

The aim of the present research was to design an element with the ability to monitor internal processes in building structures and prevent them from collapsing. As a typical element for laboratory testing there was chosen a concrete column, which was repeatedly subjected to load by simple pressure with continual monitoring of changes in electrical properties.

***Keywords*****—**Carbon, conductivity, loading, monitoring.

## I. Introduction

THE Research Institute for Building Materials focuses on cement-based building materials reinforced with fibers almost for 20 years. The main interest is in glass-fiber reinforced concrete (GFRC), which is used for the range of applications, such as light-weight facing panels and various architectural elements up to channels for deposition of high-voltage cables in tunnels of the Prague Underground. The other utilization of fibers is for cement-based composites for high-temperature application. In this case carbon fibers are successfully used.

Recently a research team in co-operation with experts from the Faculty of Electrical Engineering and Communication in the Brno University of Technology developed modified cement matrixes with effective amount of carbon particles and fibers for a design of electrically conductive elements for special purposes.

Proposed applications were heating of trafficable surfaces and shielding of electro-magnetic fields between cables of different voltage.

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These outputs are utilized also for a new aim to monitor internal states connecting to mechanical strains in concrete structures under mechanical loading. For this reason it was necessary to design special fiber-cement elements able to transfer any mechanical impulse to an electrically-measured signal detected as a change in electrical resistance with computer outputs.

As carbon particles there were used expanded or micronized graphite, fibers were on the base of polyacrylnitril (PAN) or pitch. The optimal variants were used for preparation of one-dimensional specimens most suitable for measurement of simplified impact of stress and strain.

## II. Carbon Materials Suitable for Concrete Conductivity Improvement

Glass fiber reinforced concrete was taken as a standard and modified with an addition of carbon particles and other suitable materials to enhance its electrical conductivity and broaden application possibilities of thin-walled fiber-reinforced inorganic composites for elimination of electromagnetic field effect, heating of concrete trafficable surfaces and monitoring of building structures.

In the course of searching for suitable components there were selected mainly various kinds of micronized or expanded graphite with particle size in micro- or nanometers, which is characterized by excellent electrical properties as well as good compatibility with a cement matrix, except for higher demand of batch water due to its bulk specific surface.

Carbon black with similar properties as micronized graphite was used as well. Carbon black has elementary particles generally in a range from 10 to 100 nanometers, but during the production process individual spherical particles agglomerate in chains or clusters. Micronized graphite has carbon content above 80%; carbon black has high carbon content (99%). Expanded graphites have lower carbon content (60 – 96%).

Considering an application based on a relation between electrical behaviour and mechanical strain and reverse deformation of concrete elements, two types of fiber reinforcement (carbon and metal) were chosen too.

## III. Composite Mixtures with Carbon Particles and Fibers

All mixtures were prepared in a mixer with a stationary drum and forced movement of paddles. Standard fine-grained matrix consisting of cement, sand and fine filler with 3% of dry mixture weight reinforcement by alkali-resistant glass fibers with length 12 mm was chosen for further modifications.

The addition of carbon particles induces good electrical properties in cement-based composites. Though carbon fibers are less conductive than metal fibers, composites with carbon fibers were evaluated as better current conductors than the composites with metal fibers. It is supposed that this is due to extremely fine size of carbon fibers which provides more effective inter-fibre continuity. Thus further research was carried out with carbon particles and carbon fibers.

Basic components are as follows: carbon fiber CF, micronized graphite MG, expanded graphite EG and nickel-coated expanded graphite EG/Ni. Carbon particles suitable for given applications have size from 0.01 to 100 µm.

During the tests suitability of fine-grained particle and fiber combination was confirmed. The proportion of carbon particles was expressed as a percentage of a dry mixture weight (cement + sand + fine filler) as a substitution of a part of sand in range of 4–10% per weight. Carbon fibers with diameter 18 µm and length 10 mm substituted for glass fibers up to 2% per weight.

### A. Influence on Workability

Fiber-cement mixtures were prepared in order to achieve optimal workability and minimal impedance, i.e. maximal conductivity. To compare an influence of the type of carbon on impedance of the cement-fiber composite, each carbon powder replaced the same proportion of dry components.

Carbon origin as well as particle size both affect impedance properties of the final composites, and as well the particle size affects workability of fresh mixtures. It was found that the finer carbon powder, the lower was the impedance and the worse mixture workability.

Carbon particles should be properly dispersed among other mixture components without bleeding during transport and molding. With carbon fibers the perfect defibering and ideal anchoring in binder should be reached [1].

### B. Mixture Optimization

Within the optimization process fine fillers were withdrawn from the composition. Despite the positive effect on dense structure and better mechanical characteristics of composites, pozzolanic admixtures increase electric resistance of concrete mixtures [2].

All samples were cured in laboratory conditions close to real manufacture conditions with temperature 25°C and humidity 55%. The physical-mechanical properties of composites were tested on standard samples for thin-walled GFRC elements with dimensions 250 mm × 50 mm × 10 mm in the age of 28 days. Higher water/cement ratio causes significantly higher absorption and lower bulk density, associated with low flexural strength and impact strength of the final composites.

TABLE I
BASIC MIXTURE COMPOSITIONS

| Mixture components | CF | MG | EG | EG/Ni |
|---|---|---|---|---|
| cement binder | 54% | 54% | 54% | 54% |
| silica filler | 40% | 34% | 36% | 35% |
| fine filler | 3% | 3% | 3% | 3% |
| glass fiber | 1% | 1% | 1% | 1% |
| carbon fiber | 2% | 2% | 2% | 2% |
| micronized graphite | - | 6% | - | 3% |
| expanded graphite | - | - | 4% | - |
| nickel-coated expanded graphite | - | - | - | 2% |

## IV. Measurement of Electrical Properties

Ions in pore solutions cause conducting of electric current in concretes. Conduction of electrical current in cements and concretes is essentially electrolytic. In order to avoid problems of polarization, alternate currents are often used for determining resistivity of electrolytes and therefore also of cements and concretes [3]. Therefore electrical resistance of composite materials is expressed as impedance. Percolation threshold expresses minimal concentration of the certain component that creates the first conductive way through the whole volume of measured composite [1]. In the end percolation threshold of carbon fibers was determined to 0.75% of the dry mixture weight.

In order to optimally assess the electrical parameters an influence of voltage and A.C. frequency was observed. The influence of voltage was evaluated as non-relevant. The influence of A.C. frequency on the calculated values of impedance was reasonably significant. The impedance dramatically decreased with increase in the applied frequency.

Consequently, frequency of 20 kHz was adopted as the measurement frequency and the calculated impedance was assumed equal to the resistance.

## V. Application of Proposed Elements

### A. Electro-Magnetic Shielding

Electro-magnetic field is assumed to be a problem in the so called “sick house syndrome”. External electro-magnetic fields can cause problems both in human health and in industry, where it can interfere with production of electronic equipment.

Standard glass fiber reinforced concrete inhibits electro-magnetic field up to approximately -5 dB but our modified fiber-cement composite is able to achieve a level up to -35 dB. In comparison to a massive steel reinforced concrete the same shielding effect is achieved with using of incomparably less structural thickness.

In order to approach real conditions as much as possible the measurement was carried out in a special electro-magnetic chamber. Shielding efficiency was proven by the non-availability of any communication network in the chamber [4].

A modified fiber-cement mixture was used for manufacturing of a concrete channel to demonstrate the application of electro-magnetic shielding. It contains three chambers to separate electric cables with different voltage so that they do not interfere with each other.

### *B. Concrete Heating*

Electric heating of pavements and other surfaces is carried out by using of heating cables built into a concrete panel or a sand bed under a pavement made of asphalt or cobble-stone. Heat is generated along the whole cable body by the means of direct electric energy transformation in their cores. Within accumulation systems electric input 180 – 250 W/m$^2$ is needed. According to our measurements it has been concluded that for direct heating systems only about 1 third or 1 half (80 – 130 W/m$^2$) is sufficient for the equal heat output.

A trafficable steel reinforced concrete panel was made with the ability to thaw snow cover or to defrost ice for reduction of slipping hazard on pavements or access ramps in front of buildings. The proposed element combines advantages of the solid bearing steel reinforced concrete and those of a thin fiber-cement slab with the required heating capacity.

## VI. Monitoring of Concrete Structures

The aim of the present research was to design an element with the ability to monitor internal processes in building structures and prevent them from collapsing. Any change in mechanical loading is immediately recognized and transferred into a measurable electric signal with a computer output.

For monitoring of concrete elements under loading there are used mostly tenzometers. Tenzometer actually measures only relative deformation.

It was concluded that cement composites with carbon fibers are suitable for monitoring of transition actions caused by change of strain, stress, temperature or humidity. Electrical resistance monitoring is a suitable way for characterization of cracks in concrete structure [5]. Besides ceiling panels, columns or foundations these elements could be implemented into the overloaded parts of bridge constructions.

Within experimental tests on flexural strength selected samples with effective carbon addition provided measurable changes in the impedance. For the purpose of monitoring in conditions close to a real application a model of steel reinforced concrete was made. The model was used for evaluation of electrical properties of the embedded element.

### *A. Testing of Modified Samples*

Planar samples were evaluated as inconvenient for monitoring of electrical response in individual directions of building elements for the reason of combined impact of stress and strain. Therefore the elements were designed in the shape of prisms with one dominant dimension comparing to others to avoid multi-parametrical loading effect.

These specimens were made in two dimensions 40 mm × 40 mm × 160 mm or 20 mm × 20 mm × 100 mm. In one set there was 1 element with 2 copper contacts ca. 2-5 mm from the end as shown in Fig. 1. The other 2 elements were intended for testing of physical-mechanical characteristics, i.e. compressive, flexural and tensile strength, bulk density and absorptivity.

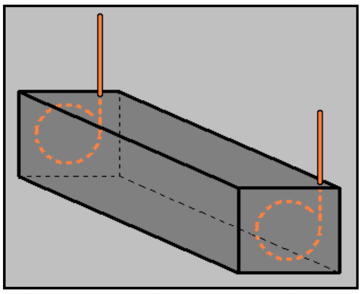

Fig. 1 Design of modified sample

Impedance measurement of individual samples was conducted under following conditions: alternate voltage 1 V and frequency 1 kHz were set to avoid corrosion of used copper electrodes, because cement composites adopt behaviour of solutions due to their internal moisture. Maximal loading 1 kN was set within the measurements to avoid unexpected damage of samples (Fig. 2).

Fig. 2 Evaluation of electrical properties under loading

### *B. Design of Concrete Column*

Relation of deformation to impedance of composite elements has been already verified [6]. The next logical step was evaluation of this relation in the practical utilization.

For evaluation of utilization of integrated composite elements in concrete or reinforced concrete column a model in standard cross section was designed. For the purpose of loading simulation in the column by the means of hydraulic press machine it was necessary to shorten its length. Therefore the final dimensions were 300 mm × 300 mm × 500 mm. There were 2 variants – the first column without steel reinforcement and the second one with steel reinforcement for comparison (see Fig. 3).

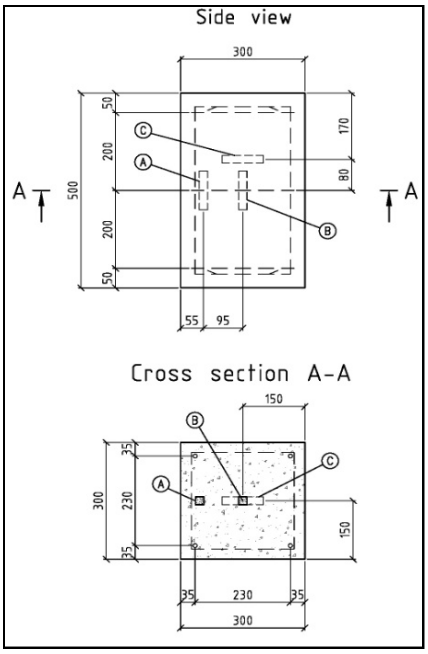


Fig. 3 Design of the concrete column with element placement and steel reinforcement

In both variants 3 composite elements were put into the model column. The first one was placed vertically in the column centroid, the second one was placed horizontally above the first one and the third one was placed again vertically at the side of the column next to steel reinforcement. The similar placement was used for the variant without reinforcement. The aim was to compare effect of the steel reinforcement and a different position of individual composite elements.

*C. Production of Concrete Column*

A mold from water-proof plywood was made according to common praxis of the column production in the horizontal position. The composite elements were fixed in the mold by the means of plastic strips to distance elements for the steel reinforcement (see Fig. 4).

Fig. 4 Mold with the composite elements and steel reinforcement

The concrete models were made from concrete C30/37 XC4 S4 D22 compacted by inner vibrators.

*D. Measurement of Impedance and Deformation during Loading*

Model columns were supplemented by plugs for deformation measurement. Digital deviation indicators were fixed to the plugs [7]. Digital impedance detectors with generated alternate voltage of 1 V were fixed to cable outlets of the composite elements. Loading of the model columns was simulated by the means of the hydraulic press machine (Fig. 5). Applied force reached values of 0 to 1,500 kN, which corresponds with pressure 16.7 MPa.

In the graphs in Figs. 6 and 7 we can see impedance of the composite elements and strain in the model columns in the course of loading in time of reaching 200 kN (2.2 MPa) by hand operation and 5x 1,500 kN (16.7 MPa) in automatic mode and again de-loading to 200 kN.

Both graphs show clear impedance change of the composite elements corresponding with changes of unit strain in the model columns.

## VII. Conclusion

It was concluded that special fiber-cement composites are able to conduct electric current under specific conditions. This property is ensured by using of various kinds of carbon materials in a form of dispersive particles or fibers. Electric conductivity is monitored by the means of impedance measurement of the designed samples. These composites could be used for heating of trafficable surfaces or shielding of electro-magnetic fields.

It is also possible to monitor internal processes in building structures and prevent them from collapsing. For this application it is necessary to design one-dimensional elements to simplify the combined loading in the structures.

Relation of impedance of the composite elements to unit strain in the model columns was successfully verified thereof. Positions of the composite elements in the models did not significantly affect monitored changes in impedance. It connected only to the absolute change of impedance, but not to the sensitivity to change detection.

The ability to transform unit strain to change in impedance seemed to be a material parameter independent on shape and orientation of the composite elements. The steel reinforcement could affect impedance of the composite elements only in some cases.

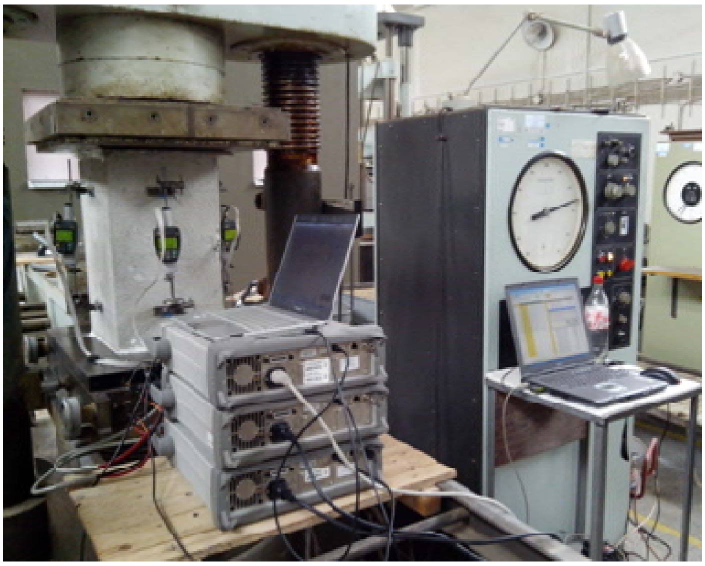

Fig. 5 The model column in the hydraulic press machine connected to the equipment monitoring changes in deformation and impedance

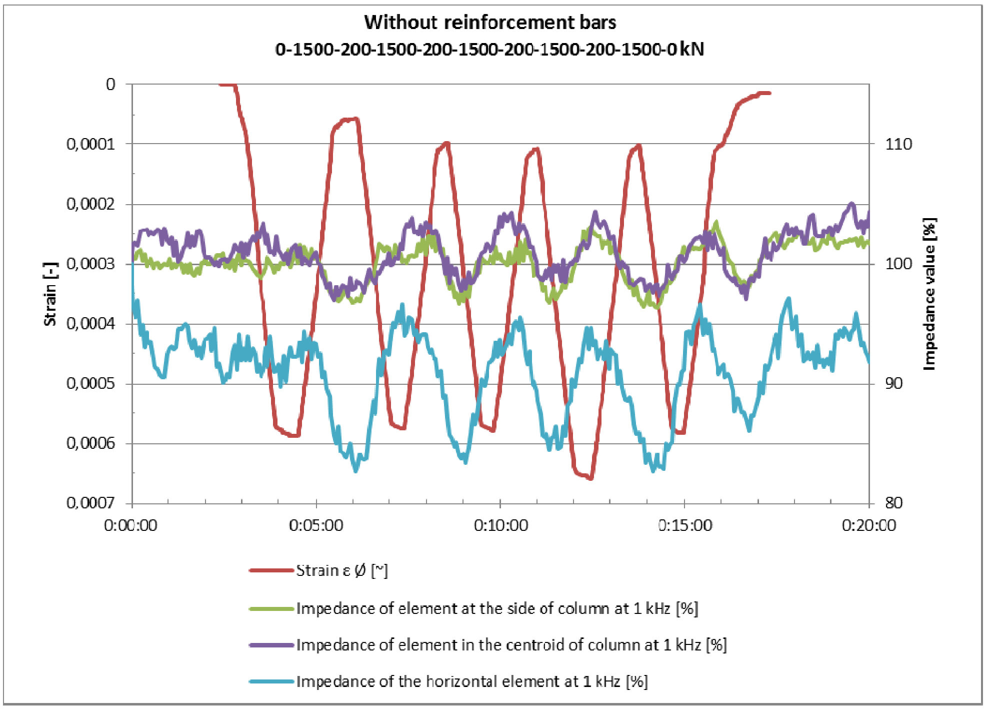


Fig. 6 Graph of strain and impedance in the course of loading for the unreinforced column

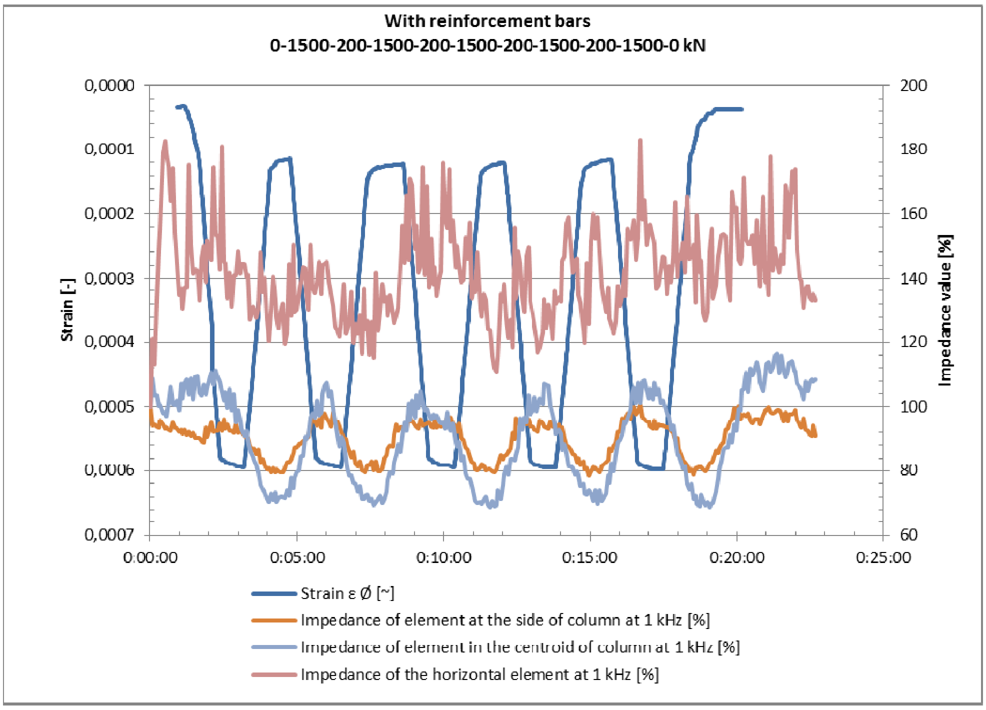


Fig. 7 Graph of strain and impedance in the course of loading for the reinforced column


## ACKNOWLEDGMENT

This paper was elaborated in the frame of the project FR-TI3/485 Engineering structure state monitoring by the means of electrically conductive elements with modified cement matrix.


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