MONITORING OF CONCRETE STRUCTURES BY THE MEANS OF FIBRE-CEMENT ELEMENTS

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Abstract

Regarding previous research studies it was concluded that thin-walled fibre-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 fibres. Though carbon fibres are less conductive than metal fibres, composites with carbon fibres were evaluated as better current conductors than the composites with metal fibres. 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 further research is to design an element with the ability to monitor internal processes in building structures and prevent them from collapsing.

Keywords: Fibre-cement composite, electric conductivity, loading, monitoring

1. Introduction

The Research Institute for Building Materials focuses on cement-based building materials reinforced with fibres almost for 20 years. The main interest is in glass-fibre reinforced concrete, which is used for the range of applications, such as light-weight facing panels, architectural elements up to channels for deposition of high-voltage cables in tunnels of the Prague Underground. The other utilization of fibres is for cement-based composites for high-temperature application. In this case carbon fibres 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 fibres for better electrical conductivity achievement. 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 fibre-cement elements able to transfer any mechanical impulse into electrically-measured signal detected as a change in electrical resistance with computer outputs.

As carbon particles there were used expanded or micronized graphite, fibres were on the base of 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.

2. Carbon materials suitable for concrete conductivity improvement

Glass fibre 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 fibre-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.

As a secondary compound carbon black with similar properties as micronized graphite was used. Basically it is composed of elemental carbon but is less structured than graphite. 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 fibre reinforcement (carbon and metal) were chosen too.

3. Proposed fibre-cement mixtures with carbon particles and fibres

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 microsilica with 3% of dry mixture weight reinforcement by alkali-resistant glass fibres with length 12 mm was chosen for further modifications.

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

Basic components are as follows: carbon fibre 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.

Tab.1: Basic mixture compositions

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

During the tests suitability of fine-grained particle and fibre combination was confirmed. The proportion of carbon particles was expressed as a percentage of a dry mixture weight (cement + sand + microsilica) as a substitution of a part of sand in range of 4 – 10% per weight. Carbon fibres with diameter 18 μm and length 10 mm substituted for glass fibres up to 3% per weight.

3.1 Influence on workability

Fibre-cement mixtures were prepared in order to achieve optimal workability and minimal impedance, i.e. maximal electrical conductivity. To compare the influence of the type of carbon matter on impedance of the cement-fibre composite, carbon powder always 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 its workability.

Carbon particles should be properly dispersed among other mixture components without bleeding during transport and moulding. With carbon fibres the perfect defibering and ideal anchoring in binder should be reached [1]. Alternatively a utilization of chopped fibres from rovings or whole strands could be recommended.

3.2 Mixture optimization

For optimization of mixtures we have tried e.g. reduction of water/cement ratio, elimination of plasticizer dosage or elimination of carbon particles and fibres. Within the optimization process a fine filler was 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 250×50×10 mm in age of 28 days. Higher water/cement factor causes significantly higher absorption and lower bulk density, associated with low flexural strength and impact strength of the final composites.

4. 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 the 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 fibres was determined to 0.75% of the dry mixture weight.

In order to optimally assess the electrical parameters the 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 found to be reasonably significant. The impedance decreased dramatically with increase in the applied frequency leveling off to approximately constant values at frequencies greater than about 9 kHz. Consequently, a frequency of 20 kHz was adopted as the measurement frequency and the calculated impedance was assumed equal to the resistance.

5. Application of proposed elements

5.1 Electromagnetic shielding

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

Standard glass fibre reinforced concrete inhibits electromagnetic field up to approximately -5 dB but our modified fibre-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 electromagnetic chamber. Shielding efficiency was proven by the non-availability of any communication network inside the chamber [4].

A modified fibre-cement channel was manufactured to demonstrate the application of electromagnetic shielding. It contains three chambers to separate electric cables with different voltage so that they do not interfere with each other.

5.2 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 fibre-cement slab with the required heating capacity.

Production of the prototype element proceeded in 3 steps. Firstly a bearing layer reinforced by a steel mesh was made. Secondly, the heating slab was embedded and fixed including boxes for thermal junctions. Finally a concrete cover was cast and compacted. The field test was carried out in the winter of 2010.

Because conduction of electrical current in concretes is essentially electrolytic, it is necessary to use alternating current for determining the resistance of concretes. Most applications of electrically conductive fibre-cement composites require a safe working voltage. For this reason it is necessary to achieve the impedance of only 4 – 10 Ω.

5.3 Monitoring of concrete structures

The aim of the further research is 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 measurable electric signal with computer output. For monitoring of concrete elements under loading there are used mostly tenzometers. Tenzometer actually measures only relative deformation and mechanical strain has to be calculated from this deformation.

During the current research it was concluded that cement composites reinforced with carbon fibres are suitable for monitoring of transition actions caused by the change of stress, strain, 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 impedance. For the purpose of monitoring in conditions close to real application a model of steel reinforced concrete structure was made. The model is used for evaluation of electrical properties of the embedded element as well as influence of concrete mass on these properties.

First experiments were made with samples of thickness 10 mm under repeated loading up to 60 kN. Impedance was measured by the means of RLC-meter Agilent E4980A. Samples with positive response were exposed to dynamic loading with frequency 1 and 5 Hz.

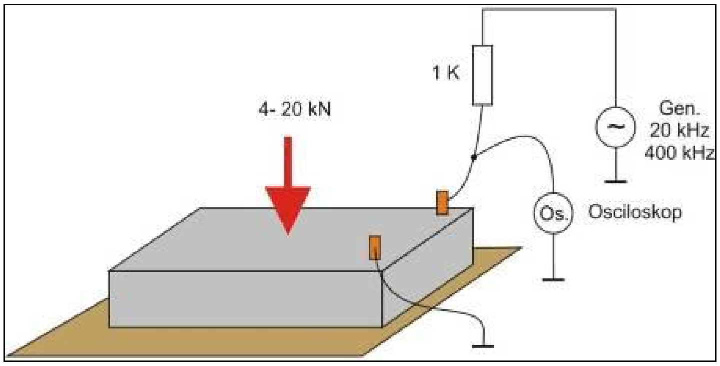

Fig. 1: Scheme of planar sample testing under cyclical loading

5.4 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. Building structures are designed to carry compressive stresses whereas steel reinforcement carries tensile stresses.

According to this conclusions laboratory tests with one-dimensional specimens were conducted. These specimens are made in two dimensions 40×40×160 mm or 20×20×100 mm. In one set there is 1 element with 2 copper contacts ca. 2-5 mm from the end. The other 2 elements are intended for testing of physical-mechanical characteristics, i.e. compressive, flexural and tensile strength, bulk density and absorptivity

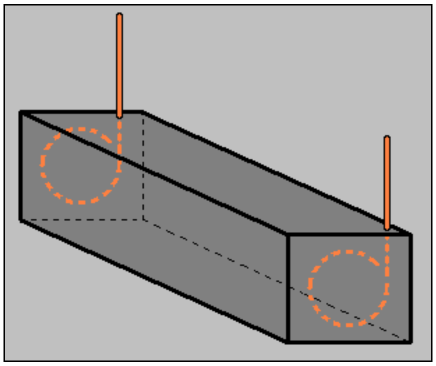

Fig. 2: Design of modified sample

Impedance measurement is 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.

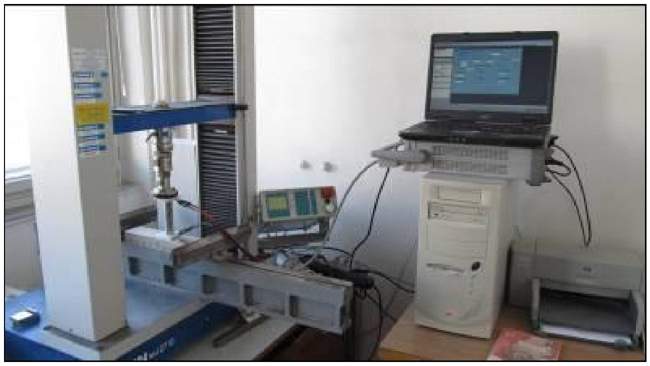

Fig. 3: Evaluation of electrical properties under loading

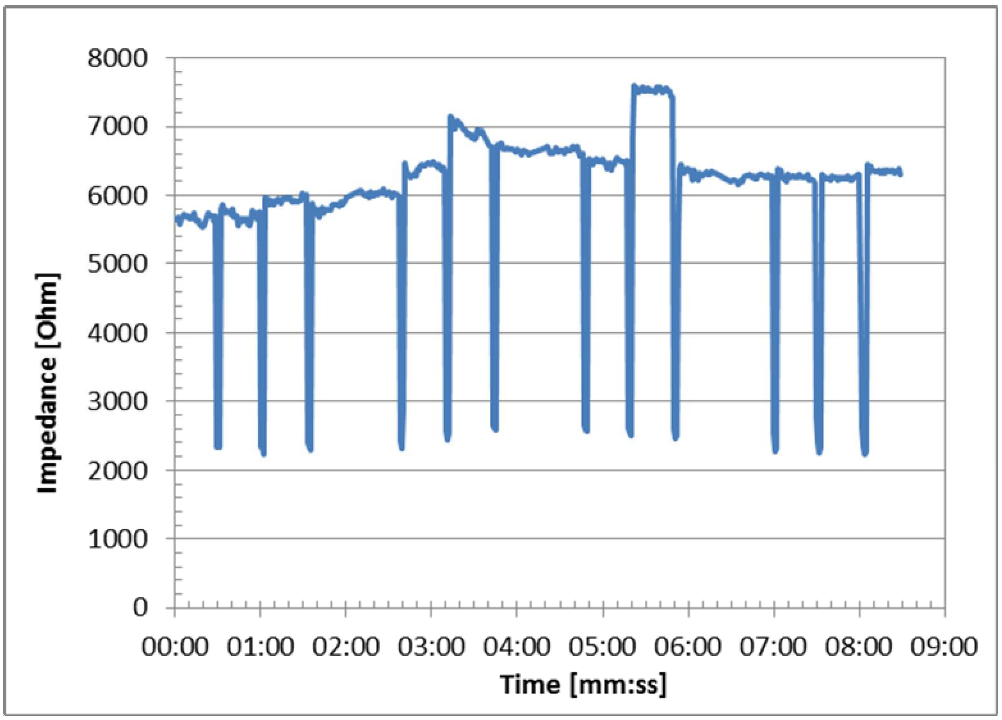

Fig. 4: Evolution of impedance under repeated loading

6. Conclusions

It was concluded that special fibre-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 fibres. Electric conductivity is monitored by the means of impedance measurement of 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.

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