FORMULATIONS OF ELECTRICALLY CONDUCTIVE CEMENT-BASED COMPOSITES

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Abstract

Basic cement matrix was modified by 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 scanning of moving vehicle weight. One of targets of the project "Multifunctional composites of extraordinary properties on the base of inorganic nanocomponents" was to achieve the greatest electrical conductivity of a composite with minimal reduction of physical mechanical properties caused by addition of carbon particles. The paper deals with particular examples of applications for electrical cable line shielding and slipping hazard elimination on communications.

Keywords: Cement composite, carbon, conductivity, electromagnetic field, heating

1. Introduction

Thin-walled cement composites reinforced with dispersed fibres find today increasing markets in all spheres of building industry: especially facing panels, U-shaped channels for high-voltage cables and variously shaped architectural elements. Such composites minimize production, transport and assembly costs and have high resistance to weather impact and therefore long lifetimes.

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. In order to achieve the specified electrical properties we mostly studied suitable carbon particles.

Petrographic shungite, known for its benefits for various branches of industry including

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this matter, cannot easily be obtained with the required quality (granulometry) and amount. Therefore a basic research was carried out with a selected type of petrol coke powder.

In the course of searching for suitable components there were selected mainly various kinds of micronized 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 of higher demand of batch water due to its bulk specific surface. The graphite structure consists of several layers of carbon atoms in hexagonal configuration. Each carbon atom is linked to next 3 carbon atoms and a large system of electrons is created. Individual layers connect to each other only by weak interactions the so called van der Waals forces. This material is commonly used for production of electrodes, brake linings, blackleads and technical lubricants.

As a secondary compound carbon black with similar properties as micronized graphite was used. It consists of above 97 % amorphous carbon. 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. It can contain another secondary compound, expanded graphite.

Fig. 1: Electrically conductive materials: micronized graphite, expanded graphite, carbon fibres, metal parings

Test composite materials can be divided according to the type of carbon matter as follows: micronized graphite (grey in graphs), carbon black (black in graphs), and expanded graphite (white in graphs).

Figure 2 shows the median particle size of the carbon powdered admixtures on a logarithmic scale for clarity. The size of particles of micronized and expanded graphite is in micrometers, while the particle size of carbon black is in nanometers. For comparison average particle size of a plain matrix consisting of cement, fine-grained sand and microsilica is in the graph given for the standard GFRC, produced in the Research Institute of Building Materials, JSC, marked as NK2.

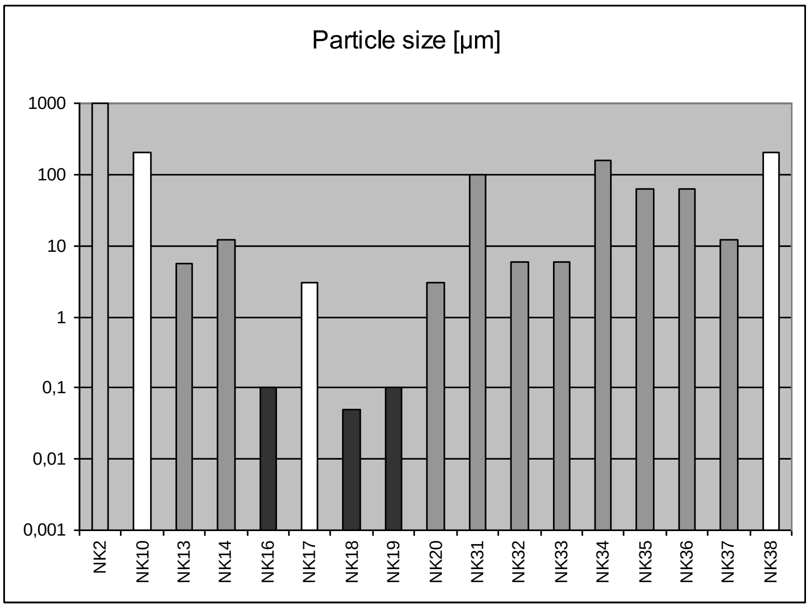

Fig. 2: Particle size of carbon admixtures - a logarithmic scale

Micronized graphite has carbon content above 80 %, carbon black has high carbon content (99 %). Expanded graphites have lower carbon content (60 – 96 %) (Figure 3).

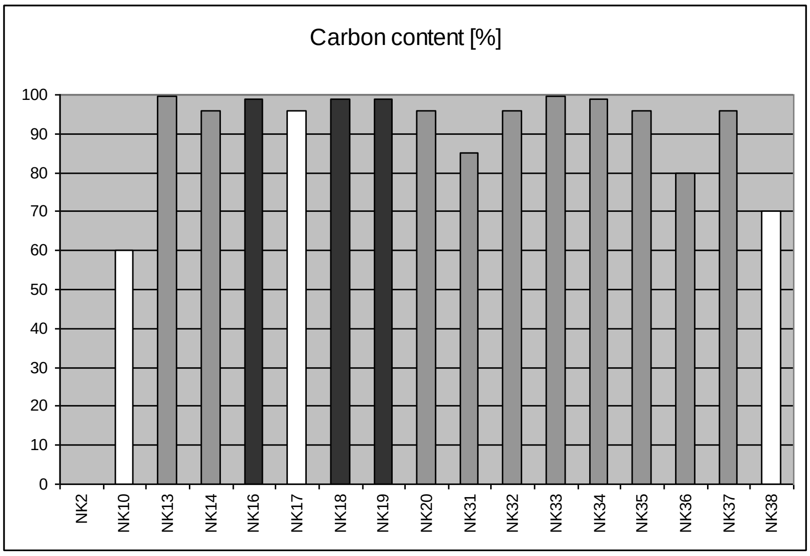

Fig. 3: Carbon content of carbon particles

Some compounds were modified to decrease interfacial tension and increase surface wettability for achievement of better mixture workability of cement composites by the means of surface treatment of nickel or Teflon. However due to high demanding preparation it was concluded that utilization of these modified carbon powders for electrically conductive composites is too expensive.

For electromagnetic shielding metal parings - mixture of various metals arisen as a scrap during cutting, shaping and drilling - were proven good as well.

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. Cement composites with addition of carbon materials

3.1 Test mixtures

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.

1. composition with use of carbon particles - average size 50 μm

– substitution 15 % per weight of a dry plain mixture

2. composition with use of carbon fibres - length 10 mm

– addition 0.8 % per weight of a dry plain mixture

3. composition with use of metal amorphous flexible fibres - length 30 mm

– addition 2.0 % per weight of a dry plain mixture

According to our measurements following statements could be concluded. 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.

3.2 Proposed fibre-cement mixtures with carbon particles and fibres

Carbon particles suitable for given applications have size from 0.01 to 100 μm. The proportion of carbon particles is 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. In the case of electromagnetic shielding metal parings were used in proportion of 3 – 10 % per weight. Carbon fibres with diameter 18 μm and length 10 mm substituted for glass fibres up to 3 % per weight.

3.3 Influence on workability of fibre-cement mixtures

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.

Appropriate mixture workability was achieved by the addition of various kinds of polycarboxylate-based superplasticizers. For wettability improvement addition of ethyl alcohol was used as well. Higher addition of plasticizer (up to 6 % per cement weight) improves workability, but it slows the mixture hardening and solidification. Therefore the plasticizer addition is the same for all mixtures and consistency of the mixture is regulated only by the amount of water in the mixture. Physical-mechanical properties of the final composite materials are closely connected to water/cement factor of the mixtures. Metal fibres require a lower water-cement ratio than carbon fibres and the highest water-cement ratio is needed for compositions with carbon particles.

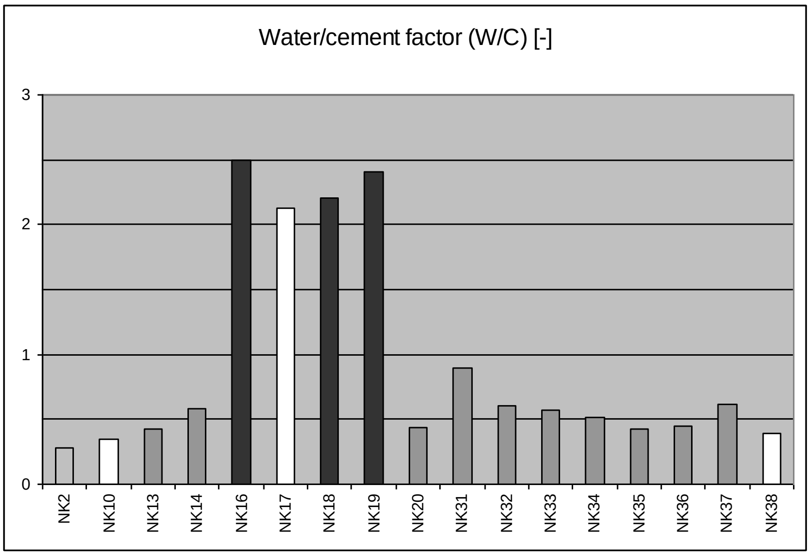

Fig. 4: Water/cement factor of prepared mixtures

3.4 Influence on physical-mechanical characteristics of composites

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. Generally bulk density is 1750 – 1800 kg/m^3, water absorption 15 – 20 %, flexural strength 10 – 12 N/mm^2 and impact strength 3 – 5 kJ/m^2.

4. Measurement of electrical properties

Conduction of electrical current in cements and concretes is essentially electrolytic. Consequently, chemical reactions take place at the electrodes, hydrogen and oxygen gases are released and form a thin film around the electrodes. This creates a polarization potential opposing the flow which manifests in reduced current for given applied voltage. 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. It was supposed that the polarization effects within the alternate current passing are not eliminated but rather manifested in a different form [1]. Therefore electrical resistance of composite materials is expressed as impedance.

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.

During the solution it was found that the impedance of the final composite is affected by a number of factors. These factors can be divided into internal and external. Internal factors include the mixture composition and method of its preparation. External factors could be e.g. moisture and temperature of environment. They have significant influence on measured values, therefore these parameters are needed to be taken into account during measurements. The impedance in the Figure 5 is also displayed in a logarithmic scale for better comparison.

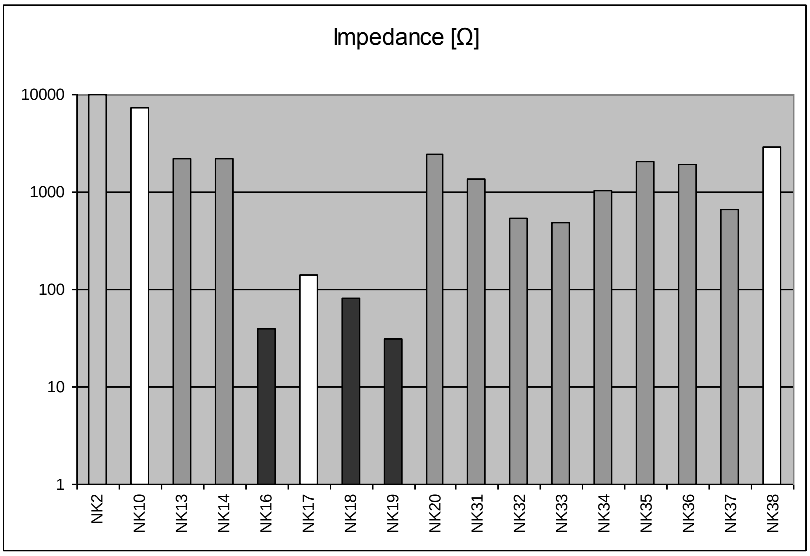

Fig. 5: Impedance in a logarithmic scale

5. Applications of proposed composites

5.1 Application of 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. It is possible to reduce the electric (electrostatic) field by the means of a metal shield such as the so called Faraday cage. For electromagnetic shielding litharge glass is also used, e.g. by micro-wave ovens or X-ray machines. By contrast it is possible to protect equipment from direct magnetic field by the means of a ferromagnetic shield.

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 [2].

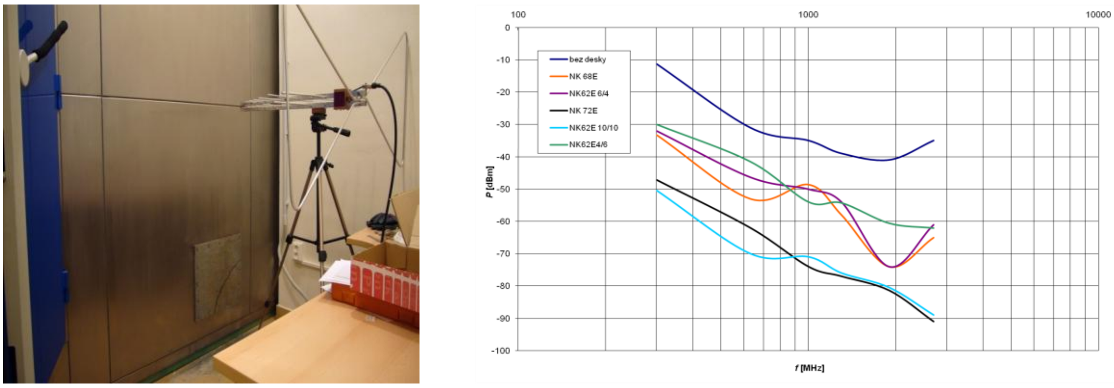

Fig. 6: Measurement in the electromagnetic chamber

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.

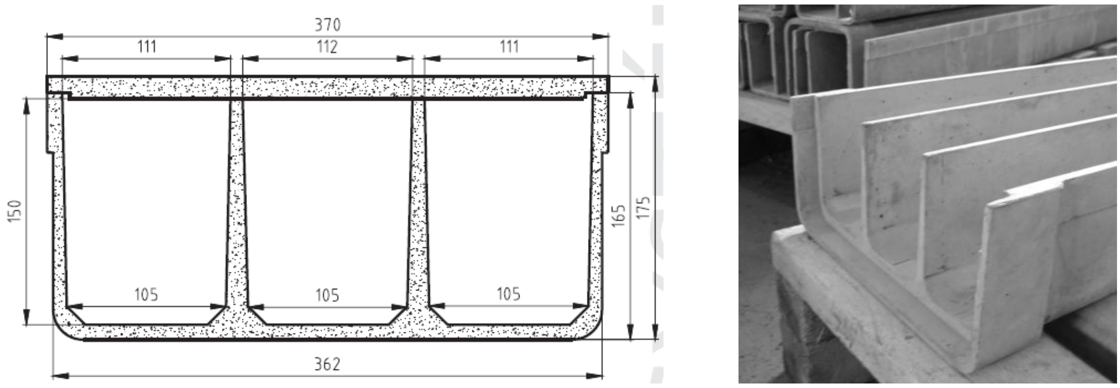

Fig. 7: Electromagnetic shielding between cables

5.2 Application of 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 about 1 third or 1 half (80 – 130 W/m^2) is sufficient for the equal heat output. For this input it is necessary to achieve impedance of only 4 – 10 Ω. The main disadvantage of the heating cables is a difficult and time-demanding cable fixing to a defined position. On the other hand the embedding of a heating fibre-cement composite slab directly in-situ is very easy.

5.3 Production of heating slab

A fibre-cement slab with dimensions 1800 × 1400 mm, thickness 20 mm and circle openings with diameter 110 mm for better incorporation into a concrete panel was cast with the designed composition. An initial setting of openings in square lattice (Figure 8) caused heating to occur only in stripes and not across the whole surface, therefore an optimisation had to be done. After thermo-camera monitoring an orthorhombic setting of openings (Figure 9) was evaluated as the most suitable for uniform heating ability.

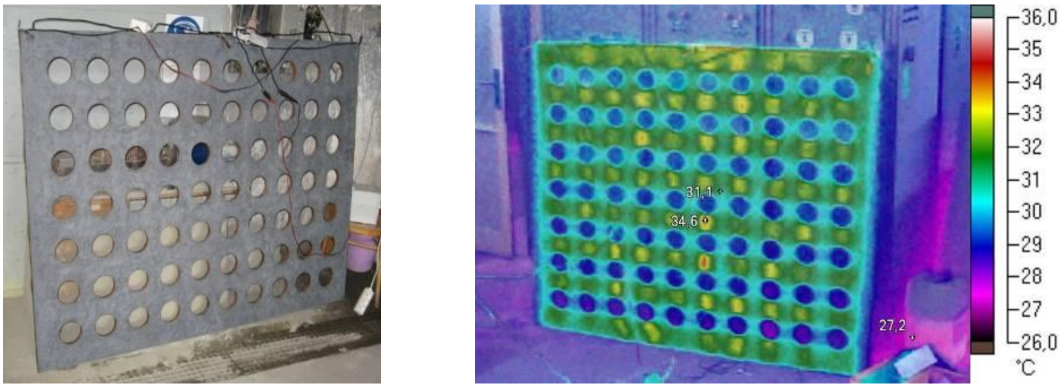

Fig. 8: Initial setting of openings

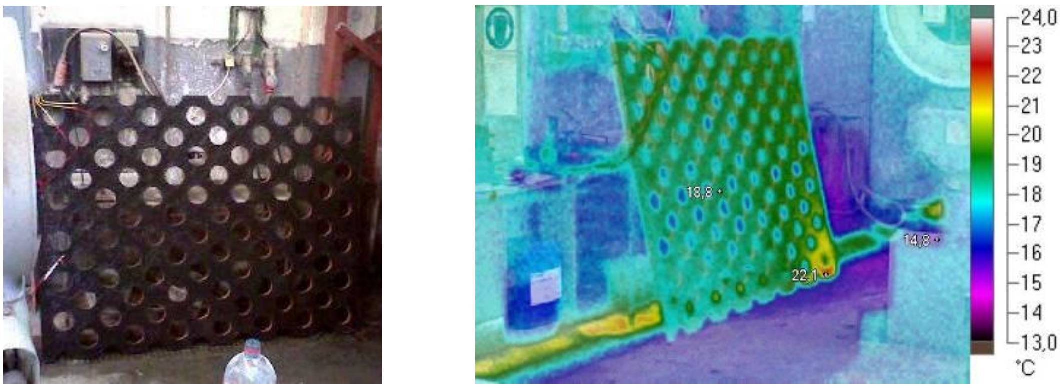

Fig. 9: Final setting of openings

5.4 Construction of tempered concrete panel

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.

Electrodes were made of copper wires of 10 mm^2 sectional area. To properly analyse the internal thermal processes, sensing elements were included into the composite. For safe operation the electric voltage was set to 12 V and an electrically insulating layer of epoxy resin was placed between the heating slab and the concrete panel.

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.

Fig. 10: Operation of the tempered panel in real conditions

6. Conclusions

Thin walled cement composites reinforced with dispersed fibres find today increasing markets in all spheres of building industry: especially facing panels, U-shaped channels for high-voltage cables and variously shaped architectural elements. Such composites minimize production, transport and assembly costs and have high resistance to weather impact and therefore long lifetimes.

Standard glass fibre reinforced concrete was modified by an addition of carbon particles and other materials to enhance the electrical conductivity of these cement composites. Though carbon fibres are less conductive than metal fibres, composites made with carbon fibres were evaluated as better current conductors.

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. Structurally-technical elements made of these fibre inorganic composites can shield against electromagnetic fields, transform electricity to heat or scan moving vehicle weight.

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. A trafficable steel reinforced concrete panel was made with ability to thaw snow cover or to defrost ice for reduction of slipping hazard on pavements or access ramps in front of buildings.

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7. References

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