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Development of Test Methods in the Process of Electrically Conductive Concrete Production

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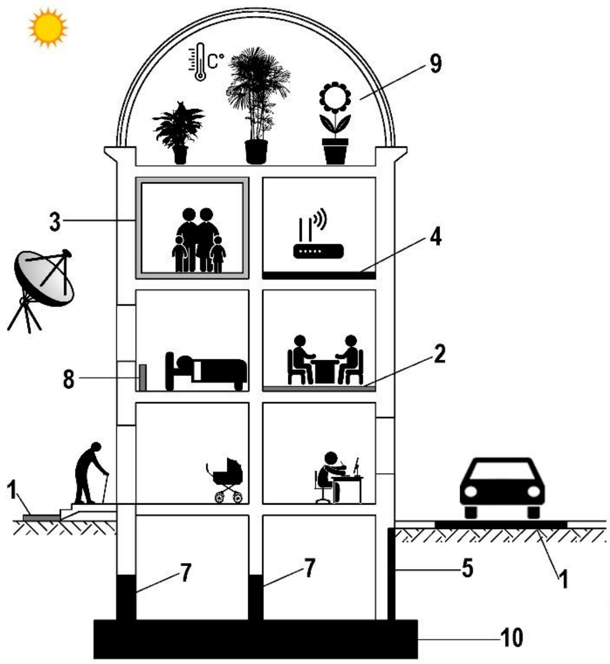
Abstract. Prevention of climate change, implementation of sustainable development principles in building industry, creation of Green buildings, Three-zero buildings (zero energy, zero emissions, zero waste), energy independent buildings maybe on the base of Smart Concrete. Electrically Conductive Concrete as type of Smart Concrete have the possibilities to create multifunctional hybrid structures for various purposes. The production of electrically conductive concrete is usually based on the introduction of carbon materials and carbon nanomaterials (CNMs) as electrically conductive fillers into its concrete composition. The theory of conductive percolation is used for design of electrically conductive concrete. To select electrically conductive carbon filler, it is necessary to summarize their electrically conductive characteristics. Today, there is no standard for determining the electrical conductivity of carbon fillers, nor is there a method for designing the composition of electrically conductive concrete; the development of both is imperative. Features of the preparation of electrically conductive concrete with hydrophobic carbon nanoparticles prone to aggregation are indicated. To obtain high quality electrically conductive products an operating system for quality control at the stages of the technological process of manufacturing must be proposed. Homogenization of the electrically conductive filler is very important. It is necessary to propose a method for assessing the stability of an aqueous suspension of a hydrophobic carbon material used for homogeneous distribution of a filler. Due to the lack of a standard, a method for determining the electrical conductivity of concrete is also needed.

1. Multifunctional electrically conductive concrete

Sustainable development in building industry, creation of Green energy independent buildings, development of hybrid multifunctional constructions for buildings and structures maybe on the base of Smart Concrete [1]. Smart Concretes, in addition to the functions of a structural material, also perform other functions that are related to their innovation properties. Smart Concrete and, in particular, Electrically Conductive Concrete (ECON), have the potential to create multifunctional hybrid structures for various purposes. These structures, in addition to the usual load-bearing and shielding functions, can perform other functions: generate, store, convert, release energy, diagnose defects and damage, protect against electromagnetic radiation, protect against corrosion under the action of stray current and much more (Fig. 1).



№	Multifunctional Electrically Conductive Concrete
1	Heated highways, runways of airfields, carriage of bridges, pavements deicing and snow melting
2	Electric heating devices of volumetric and film types for buildings and structures (floors, walls)
3	Electromagnetic Pulse (EMP) Protection
4	Electrostatic discharge (ESD) Flooring System
5	Grounding switches to protect structures from stray currents and leakage currents
6	Coating of Reinforced Concrete Structures for the Electrochemical Anti-Corrosion Protection
7	Self-Sensing constructions for monitoring of technical condition
8	Thermal accumulators made of heat resistant electrically conductive concrete
9	Electrified elements of heating and ventilation systems – air heaters
10	Batteries and supercapacitors of electrical energy

Fig. 1. Multifunctional hybrid structures of electrically conductive concrete in building and infrastructure

2. The creation of electrically conductive concrete on the base of theory of conductive percolation

Ordinary concrete, dry or in a state of equilibrium moisture, is not a conductor of electric current. It exhibits conductive properties only in a water-saturated state. In this case, its conductive properties can vary by a factor of 10. This is explained by the fact that it has an ionic conductivity. When concrete is saturated with water, the easily soluble components of cement stone transition into the liquid phase and it becomes a semiconductor with a low electrical resistivity of 10 Ohm*m. Drying concrete leads to an increase in its resistance to 109 Ohm*m [2].

The binder used in concrete can be very different. Depending on its type, the following types of concrete are: polymer concrete, polymer cement concrete, concrete with a cement binder, concrete with a liquid glass binder. If analyze them from the point of view of electrical, structural and economic efficiency, the most suitable for producing of electrically conductive concrete is cement-based concrete, since it has high structural, technical and economic indicators. Therefore, work on the use of concrete for electrical purposes should be developed in the direction of using conventional cement concrete, taking into account various methods that improve its electrical properties.

The production of electrically conductive concrete is based on the introduction of electrically conductive fillers (the so-called conductive phase) into its composition. There are two types of conductive materials used as fillers for conductive concrete: metallic and non-metallic. Iron shavings and steel fiber are used as metal fillers. Carbon materials are used as non-metallic conductive fillers.

The mechanism of electrical conductivity of concrete is sufficient definitely complicated. According to literature data, charge transfer can be carried out happen in two ways: direct contact of filler-conductor particles; emission of filler electrons through the gaps between particles (tunnel effect). The conduction mechanism can be either ionic or electronic in nature.

Experience in the production and use of composite non-metallic conductors allows us to formulate the basic requirements for the conductive phase, which also apply to electrically conductive concrete.

The conductive phase of electrically conductive concrete must have:

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- the necessary electrical conductivity;
- sufficient mechanical strength;
- temperature resistance - its own electrical conductivity should have a minimal dependence on temperature;
- the ability not to oxidize during local overheating of the composition;
- not enter into chemical interaction with the binder, leading to new qualitative states and changes in the electrical conductivity of the system;
- its linear expansion coefficient should be close in value to the linear expansion coefficient of the binder.

These requirements are most fully met by varieties of carbon materials, which have found wide application for the production of composite conductors based on ceramics, liquid glass, polymers and rubber.

The phenomenon of electrical conductivity of concrete when an electrically conductive filler is introduced into its structure can be explained in terms of the percolation theory.The term "percolation" comes from the Latin «percolatio» - «filtering», «percolation», «leaking».

Significant contributions to the theory of percolation was made by the famous French physicist, Nobel Prize laureate Pierre-Gilles de Gennes. In his paper [3] he considered a crystalline lattice in the nodes of which atoms of two A (conductor atoms) or B (dielectric atoms) with relative fractions of q and 1 - q, respectively, were arranged. The probability $\theta(q)$ that the A atoms form a macroscopic (unlimited size - the so-called "breakdown" of the medium will occur) cluster in the lattice was calculated. In this case the material became a conductor, undergoing a phase transition of the second kind. He showed that at $q < q_c$ in the medium it is possible to appear only individual microscopic clusters, and at $q > q_c$, a macroscopic cluster appears, permeating the entire medium. Here q_c is the percolation threshold. For $q > q_c$ there is a phase transition of the second kind (smooth dependence of $\theta(q)$). When the material matrix is filled with an electrically conductive filler, a second percolation threshold is achieved. After it, the conductivity of the material practically does not depend on the amount of filler, but depends only on the intrinsic conductive properties of the filler (see Fig. 2).

After the material undergoes percolation ($q > q_c$), the relationship between its electrical conductivity and the filler's own conductivity, the percolation threshold, and the volume fraction is usually expressed by the following equations [4, 5]:

$$\sigma = k(q - q_c)^n \tag{1}$$

where σ is the conductive composites conductivity, k is the conductivity-related constant of the conducting material, q is the mass fraction of the conducting material, q_c is the composite percolation threshold, and n is the conductive network dimensionality critical factor.

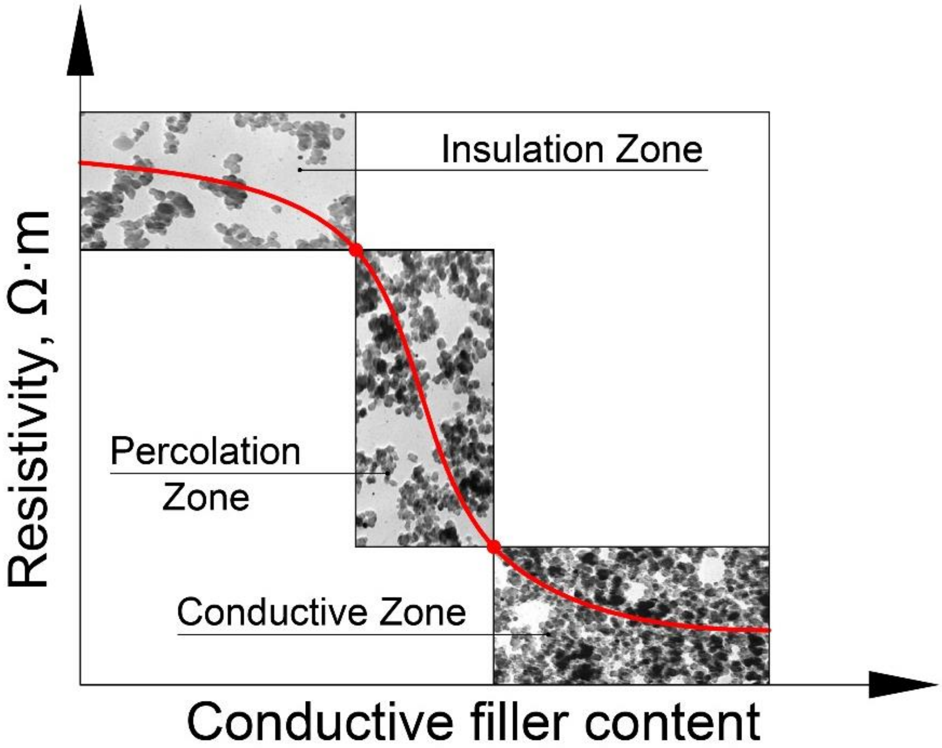

Fig. 2. Resistivity zones of electrically conductive concrete

3. Carbon materials and nanocarbon structures as fillers for creating electrically conductive composite materials

Carbon in natural and modified forms is widely used in industry.

Coke. Coal coke is a hard, grey, porous product, made from coal, peat, etc. by burning without access to air at temperatures of 950–1100°C without oxygen for 14 – 18 hours [16]. Electrical resistivity of coke beds depends of coke particle size [6], [7].

Carbon black. Carbon black is a highly dispersed amorphous carbon, a product of incomplete combustion or thermal decomposition of hydrocarbons under uncontrolled conditions. Insoluble in water [9].

Graphite. Graphites are gray-colored substances with metallic luster, greasy to the touch. Graphite is an alotoropic form of carbon, which is characterized by a certain crystal structure that has a peculiar structure. Has high electrical and thermal conductivity [10].

Graphene. Graphene is a two-dimensional allotropic form of carbon in which atoms combined in a hexagonal crystal lattice form a layer one atom thick. Single-layer graphene was explored theoretically in 1947. Graphene was discovered in 2004 by Andrei Geim and Konstantin Novoselov (University of Manchester, United Kingdom) [11]. Despite its relatively young age, graphene and its modifications are used today in many industries, including construction [12].

Carbon Fibers. Carbon fiber is a material consisting of thin filaments, 3 to 15 microns in diameter, formed primarily by carbon atoms. The carbon atoms are organized into microscopic crystals aligned parallel to each other. The alignment of the crystals gives the fiber greater tensile strength. Carbon fibers are characterized by high tensile strength, low specific gravity, low coefficient of thermal expansion and chemical inertness [13].

The experimental results of measuring the resistivity of carbon materials are shown in Table 1. The data show that the resistivity of different carbon materials differs significantly. Moreover, the resistivity of the same material, according to the research data of different authors, also differ significantly. This can be explained by the different origin of the materials, their different quality, as well as different research methods. Today, there is no standard in the world for determining the specific resistance of conductive fillers for the production of conductive concrete. Therefore, there was a need to develop a project of such a standard.

Table 1. Carbon materials and nanocarbon structures as fillers for creating electrically conductive composite materials

Fillers	Resistivity, 10^5 Ω*m	Note	Density, g/cm^{-3}	Refe-rence
Coke	170 - 220 100-160	5 - 10 mm 15 – 20 mm	0,35 - 0,77	[6]
Needle Cokes	300 - 700			[8]
Coke breeze	70000 20000 6000 4000	0-2 mm 2 – 4 mm 4 - 6 mm 6 - 8 mm		[7]
Carbon Black	20 – 100 100 – 100000 40 100 – 10000		1,8 – 2,1	[13] [14] [15] [3]
Partcally Graphite Carbon Black				
Activated Anthracite				
Nanoporous bio-carbon				
Graphite	1 3 1 30 300	ǁ plane ⊥ plane ǁ plane	1,9 - 2,6	 [13] [16] [17] [17]
Graphite Powder	770			[18]
Fine Crystalline Graphite	1			[19]
Ultrafine graphite				
Thermally expanded graphite				
Nanographite				
Graphene	0,1		1,06	[3]
High Purity Graphene (China)	70 - 100			[13]
Few layers graphene	5 - 10			[13]
Reduced Graphene Oxide	140			[13]
Graphene nanoplatelets				[18]
Carbon Nanotubes	0,1 - 1		1,3 - 1,75	[3]
Fullerenes				
Carbon Fibers(CNF)	9 200 – 2000 0,1	4 – 7 μm	2	[20] [21] [3]

4. Input quality control of materials for concrete

Cement. For cement it is need to know type and composition of cement according to manufacturer certificate. For Portland cement define mineralogical composition of cement clinker: $3CaO\ SiO_2$ (C_3S)

- three calcium silicate; 2CaO SiO_2 (C_2S) – two calcium silicate; 3CaO Al_2O_3 (C_3A) - three calcium aluminate; 4CaO Al_2O_3 Fe_2O_3 (C_4AF) - four calcium alumoferite.

Important characteristic of cement is grade, activity or its strength which is determined according to standard methods [22], [23].

Sand. Most often, quartz sand is used to produce ordinary heavy concrete. The grain (granulometric) composition of sand is an important indicator that affects the density of the concrete structure and its properties. For sieve analysis of fine aggregates use standard methods [24], [25].

Table 2 shows groups of sand by grain size.

Table 2. Sand groups by grain size

The type of sand	The fineness modulus	Total residue on the sieve (with holes of 0.63 mm), %
Increased size	3-3,5	65-75
Coarse	2,5-3	45-65
Average	2-2,5	30-45
Small	1,5-2	10-30
Very small	1-1,5	to 10

The fineness modulus of sand should be in the range of 2-2.5, and for concrete with a strength limit of 20 MPa and above, the sand fineness modulus should be at least 2, and for concrete with a strength limit of 35 MPa and higher - at least 2.5.

Electrically conductive filler. The most important characteristic of conductive filler for creating conductive concrete is the resistivity of the filler or specific electrical conductivity. Today, there are no standards for determining these characteristics. We proposed a method of testing the resistivity of electrically conductive carbon materials [26].

The essence of the method is to measure the resistance of a column of carbon nanomaterials with a fraction size of up to 10 mm, enclosed in a matrix (dielectric tube) between two electrically conductive punches under a pressure of 1 MPa while passing direct current.

Equipment. To carry out measurements, use transformer 220x12 V or battery 12 V; an ohmmeter or multimeter with a lower resistance measurement limit of at least 0.01 Ohm; laboratory press, mechanical or hydraulic, providing a pressure of 1 MPa; dynamometer; matrix (dielectric tube) with electrically conductive punches; dial indicator; thermocouple with temperature display (see Fig. 5).

Testing. The lower electrically conductive punch is inserted into the matrix. A sample of carbon material of a certain height loaded evenly into the matrix. An upper punch is inserted into a matrix. The matrix with is placed under a press through dielectric gasket. A dial indicator is installed on the mobile punch to measure the deformation (shortening) of the carbon filler. The thermocouple is installed into a matrix with a carbon material.

The controlled force providing a pressure on the material of 1 MPa (10 kgf/cm²) is equal to:

$$N = f \cdot A = f \cdot (\pi d^2/4) \quad (2)$$

Where: N – force, kgf; f – pressure on the carbon material, kgf/cm²; A - the internal cross-sectional area of the matrix, cm²; d – the internal diameter of matrix.

The loading force is determined by the pressure gauge of a hydraulic press or the dynamometer indicator of a mechanical press.

After 1 minute after applying pressure, the indicator determines the deformation (shortening) of the column of carbon material; electrically conductive punches are connected to the measuring circuit and measurements of resistance, electrical voltage, and electrical current are made; the thermocouple is connected to the temperature display for testing of carbon material temperature (see Fig. 3).

The measurements are repeated for three samples of the same batch of carbon material.

Processing the results. Determine the length of the column of compacted carbon material:

$$l = l_0 - \delta_l \quad (3)$$

Where: l - is the length of the column of compacted carbon material, m; l_0 - initial length of carbon material column; δ_l - the shortening of the column of carbon material.

The electrical resistance value of carbon material - R, ohm (Ω) is determined with an ohmmeter or using the formula of Ohm's law:

$$R = U/I \tag{4}$$

Where: R – resistance of the column of carbon material, Ohm; U – the electrical voltage in Volts, V; I - the electrical current in amperes, A.

Voltage and current are measured by instruments - a voltmeter and an ammeter.

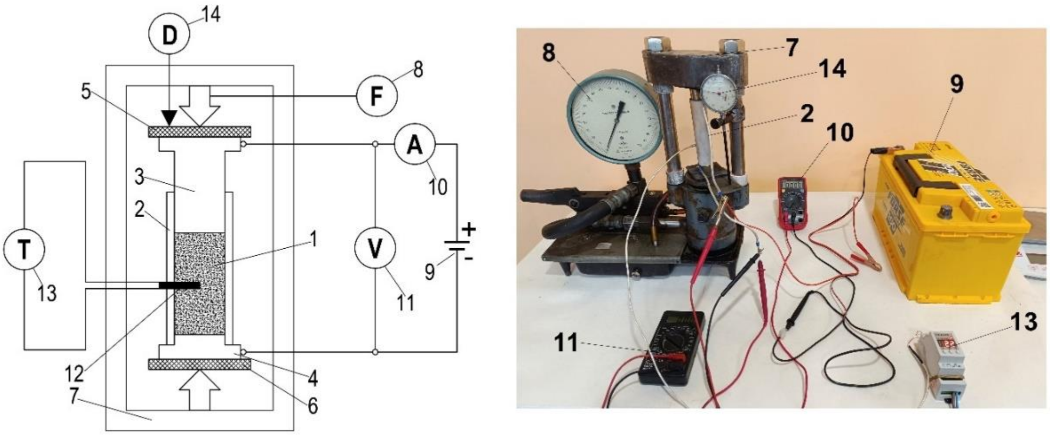

Fig. 3. Schema for testing the resistivity of electrically conductive fillers: 1 - conductive filler; 2 – matrix (dielectric pipe); 3, 4 – upper and lower conductive punch; 5, 6 - upper and lower dielectric gasket; 7 – press; 8 - force gauge of press; 9 – battery or transformer 220x12 V; 10 – ammeter; 11 – voltmeter; 12 – thermocouple; 13 - temperature display; 14 - dial indicator.

The resistivity of carbon material is determined from the relationship:

$$R = \rho \cdot (I/A) \tag{5}$$

$$\rho = R \cdot (A/I) \tag{6}$$

Where: ρ - resistivity of carbon material, (Ohm·m²)/m, Ohm·m; A – internal cross-sectional area of the matrix, m²; l - the length of the column of compacted carbon material, m.

Conductivity (electrical conductivity):

$$S = 1/R \tag{7}$$

Where: S - conductivity of carbon material, Siemens (1/Ohm).

Specific conductivity of carbon material:

$$S = 1/\rho \tag{8}$$

Where: s - is the specific conductivity of the carbon material, Siemens/m.

The final result of the resistivity or electrical conductivity of the carbon material is taken as the arithmetic mean of all measurements.

5. Mix design of fine-grained conductive concrete

Depending on the type and purpose of the structure, fine and coarse aggregates are added to the composition of electrically conductive concrete (ECON). Thus, ECON is a type of micro-aggregate concrete. The main parameters of ECON, as follows from its purpose, are electrical conductivity and mechanical strength.

The electrical resistivity of a composite conductive material will primarily depend on the volumetric concentration of the conductive phase, its granulometry or specific surface area, the electrical resistivity of the carbon material itself, and the amount of water in the conductive concrete mixture. When working with one type of carbon material and its specific granulometry, solving the problem at a given finite resistivity of electrically conductive concrete is reduced to finding the required volumetric concentration of carbon and the optimal amount of water. The concentration of the conductive phase in electrically conductive concrete will depend on the carbon: cement ratio, the separation of fine aggregate grains and its voids.

It is most difficult to identify the dependence of the electrical resistivity of electrically conductive concrete on the mixing water. The cement and carbon material included in the mixture are highly dispersed hydrophilic materials, and in order to impart the necessary mobility to the mixture, a significant amount of water must be introduced into it. At the same time, the mobility of the mixture of electrically conductive concrete is not a function of the water-cement ratio, since when the ratio of carbon material - cement changes, in order to maintain the same mobility, it is necessary to change the water – cement ratio (W/C) within significant limits. At the same time, when a certain limit of water content in the mixture is exceeded, an increase in electrical resistance is observed with a constant amount of carbon material.

The strength characteristics of an electrically conductive material depend on the same factors as for ordinary concrete, i.e., on the activity of cement and the water-cement ratio. However, this dependence is more complex due to the presence of a significant amount of finely dispersed carbon material in the system. It is most rational to design the composition of a mixture of electrically conductive concrete using the absolute volume method. The water content in the mixture must be determined experimentally in each individual case, achieving a given workability value.

The goal of the design is to establish a rational ratio of components, which will ensure the production of a fine-grained concrete mixture of the specified mobility, the providing the required strength and electrical conductivity by the concrete.

Input data for calculations of the composition of fine-grained concrete: type of concrete by purpose; compressive strength of concrete, MPa; mobility of the concrete mixture, cm; type of binder, its activity, MPA and bulk density, kg/m^3; type of aggregate and its bulk density, kg/m^3; type of conductive filler and its bulk density, kg/m^3. To determine the composition of fine-grained concrete, a calculation is made for 1 m^3 of sand. After making a test batch and testing the mixture, it is specified. The calculation is carried out according to empirical dependencies.

1. Find the amount of cement (kg) per 1 m^3 of sand:

$$q_c = f_{con} \cdot 1000/k \cdot f_c \tag{9}$$

Where: q_c - amount of cement (kg) per 1 m^3 of sand; f_{con} - specified strength of fine-grained concrete, kgf/cm^2; f_c – cement activity, kgf/cm^2; k is the coefficient when using Portland cement k = 1.

The volume of cement is determined by the formula:

$$V_c = q_c/\rho_c,\ m^3 \tag{10}$$

Where: ρ_c is the bulk cement density, kg/m^3.

We take the volume ratio of the consumption of conductive filler (further filler) to the consumption of cement and find the consumption of the filler:

$$n = V_e/V_c \tag{11}$$

$$V_e = n \cdot V_c \tag{12}$$

$$q_n = V_e \cdot \rho_e \tag{13}$$

Journal of Physics: Conference Series **2845** (2024) 012032 doi:10.1088/1742-6596/2845/1/012032

Where: V_e – filler volume; q_e - amount of filler (kg) per 1 m³ of sand; ρ_e is the bulk density of the filler.

3. The composition of the mortar of fine-grained concrete in parts is determined as the result of the ratio of the volumes of the corresponding components of the mortar to the volume of cement:

$$V_c/V_c : V_e/V_c : V_c/V_s$$

$$V_c/V_c = 1;\ V_e/V_c = x;\ V_c/V_s = y.$$

Where: Vs is the volume of sand, 1 m³.

4. The approximate amount of water per 1 m³ of sand to obtain a concrete mixture of the specified mobility is found by the formula:

$$q_w = 0{,}70(q_c + q_e) \quad (14)$$

Where: q_w is the amount of water, l.

The obtained results are used for the calculations of the test batch and then refined experimentally.

Calculation of the composition of the mortar of fine-grained concrete for a test batch with a volume of Vm l:

$$q_{cm} = V_m \cdot 1 \cdot \rho_c/(1 + x + y)\ \ (kg);$$

$$q_{em} = V_m \cdot x \cdot \rho_e/(1 + x + y)\ \ (kg);$$

$$q_{sm} = V_m \cdot y \cdot \rho_s/(1 + x + y)\ \ (kg);$$

$$q_{wm} = 0{,}70(q_{cm} + q_{em})\ \ (1).$$

Where: V_m is the volume of the test batch; q_{cm}, q_{em}, q_{sm}, q_{wm} – the consumptions for the test batch, respectively, of cement, filler, sand, and water; 1, x, y – parts of cement, filler, sand in the composition of fine-grained concrete.

The actual values of the mobility of the concrete mix are determined by the test batch, and after forming the samples and their hardening, the concrete strength and electrical conductivity indicators are determined.

6. Features of preparation of electrically conductive concrete with carbon fillers

The fabrication of electrically conductive concrete has some features. The preparation of a mixture of electrically conductive concrete is complicated compared to ordinary concrete by the fact that a large amount of finely dispersed conductive phase is introduced into it, which must be distributed as evenly as possible throughout its entire volume. Otherwise, the electrically conductive concrete obtained from this mixture will not be sufficiently homogeneous, which can sharply reduce its performance characteristics or even make it impossible to use it as an electrically conductive material.

When nanosized particles are used, agglomeration occurs, reducing dispersibility and uniformity of distribution of particles in the volume of the prepared composite. The consequence of this is a decrease in the homogeneity of the material and its physical and mechanical properties, electrical conductivity which requires the adoption of appropriate measures. Thus, an important issue and a challenging task in the application of nanomaterials is the necessity of uniform distribution of small amount of finely dispersed substance in the volume of the material to be modified.

Highly dispersed nanomaterials are prone to agglomeration due to high surface energy. In addition, almost all of these materials are hydrophobic. Hydrophobic material is a material that has the ability to repel water. Due to these features, the uniform distribution of carbon nanomaterials (CNMs) in the concrete mixture is problematic. Carbon nanomaterials can be introduced as a suspension or in dry form.

Four main methods can be distinguished for the distribution of carbon nanomaterial in the cement matrix of concrete. In the first method, an aqueous suspension of nanomaterial and superplasticizer is prepared using an ultrasonic disperser. This suspension is then introduced into the mixer while mixing cement and sand.

The second method differs from the first method in that a high-speed mixer (angular speed 3000 rpm) is used to prepare an aqueous suspension of carbon nanomaterial and superplasticizer. This suspension is then introduced into the mixer as in the first method.

In the third method dry components - cement, sand, carbon nanomaterial - are mixed in a forced-action mixer. Then, during mixing, water with pre-dissolved superplasticizer is introduced.

In the fourth method, mechanical activators (ball mills, disintegrators, process activation units) are used for homogenization of nanoparticles of electrically conductive filler in cement, where cement is mixed and activated. After activation, the activated cement-carbon mixture, sand and mixing water are introduced into the mixer and mixing takes place.

Colloidal stability of carbon nanomaterial suspension in aqueous medium can be controlled by weight method or by measuring the optical density of the suspension along the height of the working vessel at certain time intervals within the technological operation. It is reasonable to use a glass flask of sufficient height, where tests are taken by height at intervals.

In our experiments, graphene oxide as CNMs and sodium oleate as superplasticizer were used to prepare the suspension (Fig. 4). Sodium oleate was first dissolved in a container with water and then graphene oxide was gradually added and mix the suspension with high-speed mixer at 3000 rpm for 15 min.

a) b)

Fig. 4. Preparation a suspension of graphene oxide: a) - sodium oleate solution; b) -suspension

It is most advisable to prepare electrically conductive concrete using forced action mixer. Technological stages and operational quality control of manufacturing products made of electrically conductive concrete with fine aggregate are given in Table 3.

Testing of the electrical conductivity of concrete is carried out using a non-destructive method on control samples, which can then be used to control other characteristics of concrete: strength, water absorption, etc.

Equipment for testing. To carry out measurements, use transformer 220x12 V or battery 12 V; an ohmmeter or multimeter with a lower resistance measurement limit of at least 0.01 Ohm, or ammeter and voltmeter; press, mechanical or hydraulic, or clamps 200 mm; two metallic electrically conductive plates; two conductive gaskets; two dielectric gaskets (see Fig. 5).

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Table 3. Technological stages and operational quality control of products made from electrically conductive concrete

Technological stages	Control type
weight dosage of cement	activity, chemical and mineralogical composition, specific surface area, bulk mass, weight dosage
processing and weight dosage of quartz sand	the fineness modulus, moisture, weight dosage
processing (if necessary) of the conductive component - crushing, vibration grinding, screening out large fractions and weight dosing	electrical conductivity, specific surface area, particle size, bulk density, weight dosage
weight dosage of superplasticizer	weight dosage
volumetric dosage of water	volumetric dosage
preparation of an aqueous suspension of the conductive component and superplasticizer in water	homogeneity of suspension
dry mixing of sand and cement in a forced mixer	mixing time
adding the water suspension to the mixer and wet mixing the mixture	mixing time, homogeneity and stability of the mixture
laying (molding) the concrete mixture and its compaction	vibration frequency and amplitude, vibration time
exposure of products before heat treatment	exposure time
hydrothermal treatment	temperature rise rate, isothermal heating temperature, cooling rate
demoulding and finishing of products	visual
quality control of products and their storage	geometric parameters, concrete strength, concrete electrical conductivity, water absorption, frost resistance (if necessary)

Requirements for samples. Specimens from ECON must be cubes with an edge of 10 cm or 15 cm, cylinders with a diameter of 15 cm, length 15 cm or 30 cm, prisms with dimensions of 4x4x16 cm, 10x10x40 cm. The faces must be flat and ensure a tight fit of the contact electrically conductive metal plates over the entire surface. The faces of the sample in contact with the plates must be sanded.

Measurement technique. The specimen is placed between two metal (for example, copper) plates having a thickness of 3-5 mm. Ensuring reliable electrical contact between the plates and the sample is carried out using electrically conductive gaskets or pastes and a press or clamps, which are insulated from the plates with dielectric spacers.

The following can be used as electrically conductive gaskets: a) a gasket made of staniol (soft metal); b) carbon felt electrode; c) highly conductive elastomer gaskets made of silicone impregnated with silver, nickel, and other conductive materials; d) sponge impregnated 20% solution of NaCl; d) electrically conductive graphite paste.

An electrical circuit is connected to the plates and measurements are taken.

Processing the results. The specific conductivity of concrete specimen in the shape of a cube, Siemens/m:

$$s = 1/R \cdot l \tag{15}$$

Where: R – resistance of the specimen, Ohm; l - the length of the cube edge, m.

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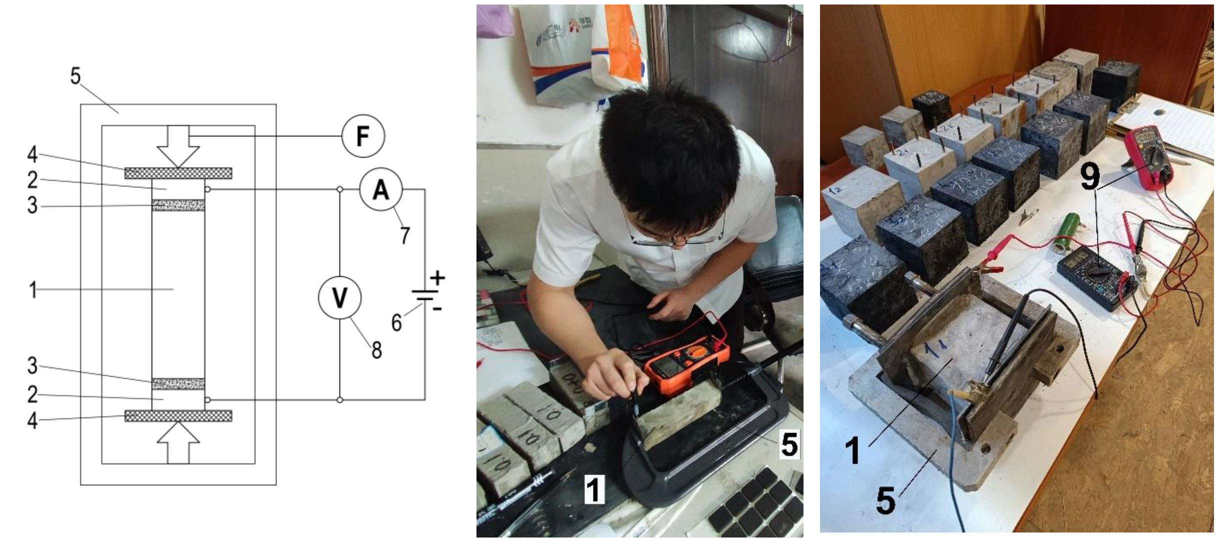

a) b) c)

Fig. 5. Testing the resistivity of concrete: a) – schema; b) - specimen in the shape of a prism; c) - specimen in the shape of a cube; 1 – concrete specimen; 2 – conductive plate; 3 – conductive gasket 4 - dielectric gasket; 5 – press or clamp; 6 – battery or transformer 220x12 V; 7 – ammeter; 8 – voltmeter; 9 - multimeter

The specific conductivity of concrete specimen in the shape of a prism, Siemens/m:

$$s = l/R \cdot A \tag{16}$$

Where: l - the height of the prism, m; A – cross-sectional area of the prism, m².

The electrical resistance of specimen - R, Ohm (Ω) is determined with an ohmmeter or using the formula (4).

Measurements are carried out for three samples of the same composition, and for each sample - a cube between all parallel faces (3 dimensions), for a prism - along the long side. The arithmetic mean of all measurements is taken as the final value of electrical conductivity. The final result of the electrical conductivity of the concrete is taken as the arithmetic mean of all measurements.

Conclusions.

Sustainable development in building industry, creation of Green energy independent buildings, development of hybrid multifunctional constructions for buildings and structures maybe on the base of Smart Concrete. Smart Concrete and, in particular, Electrically Conductive Concrete (ECON), have the potential to create multifunctional hybrid structures for various purposes. The production of electrically conductive concrete is based on the introduction of electrically conductive fillers into its composition. There are two types of conductive materials used as fillers for conductive concrete: metallic and non-metallic. Carbon materials and carbon nanomaterials (CNMs) are used as non-metallic conductive fillers. The basic requirements formulated for the conductive phase, which also apply to electrically conductive concrete: the necessary electrical conductivity; sufficient mechanical strength; temperature resistance - its own electrical conductivity should have a minimal dependence on temperature; the ability not to oxidize during local overheating of the composition; not enter into chemical interaction with the binder, leading to new qualitative states and changes in the electrical conductivity of the system; its linear expansion coefficient should be close in value to the linear expansion coefficient of the binder. The creation of electrically conductive concrete possible on the base of theory of conductive percolation. Percolation is phenomenon dramatically changing the resistivity (electrical conductivity) of the material after a certain threshold amount of introduced electrically conductive filler and concrete changes from dielectric to conductor. Based on literature sources, data on the electrical conductivity of carbon materials are summarized. Due to the lack of a standard, a method for determining the electrical conductivity of the filler has been proposed. An empirical method for designing the composition of electrically conductive fine-grained concrete is proposed. Features of the preparation of electrically conductive concrete with hydrophobic carbon nanoparticles prone to aggregation are indicated. Four main methods can be distinguished for the distribution of carbon nanomaterial in the cement matrix of concrete. A method for uniform distribution of electrically conductive nanoparticles in the form of a suspension of graphene oxide and sodium oleate as a superplasticizer has been successfully tested. Colloidal stability of carbon nanomaterial suspension in aqueous medium can be controlled by weight method or by measuring the optical density of the suspension. An operating system for quality control at the stages of the technological process of manufacturing products from electrically conductive concrete was proposed. Due to the lack of a standard, a method for determining the electrical conductivity of the concrete has been proposed.

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