Carbon materials for electrically conductive concrete

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Abstract. In recent decades, the direction of building materials science related to the creation of Smart Concretes has been rapidly developing. Smart Concretes, in addition to the functions of a structural material, also perform other functions that are related to their new properties. Among the large number of Smart Concretes, it is necessary to highlight Electrically Conductive Smart Concrete. This type of concrete is obtained by adding conductive fillers to the concrete mixture. Among them, carbon materials are the most promising in terms of their properties. Despite the large number of conducted studies of conductive fillers and conductive concrete, there is still no generalization and systematization of them. In addition, there are no standards for testing the conductive properties of both fillers and concretes. Therefore, the authors aimed to systematize data on Electrically Conductive Smart Concrete, as well as electrically conductive carbon fillers. A method for testing the electrical conductivity of Carbon Nanomaterials (CNMs) as fillers for Electrically Conductive Concrete is proposed. Approbation of the proposed method was carried out by determining the electrotechnical indicators of carbon fillers, such as coke breeze and carbon black.

1 Multifunction of Electrically Conductive Concrete

Concrete is the most widely used material for infrastructure building. Creation of energy independent buildings, development of hybrid multifunctional constructions maybe on the base of Smart Concrete [1]. 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 (Table 1).

Heated highways, runways of airfields, carriageways of bridges, pavements for deicing and snow melting. Many transportation agencies allocate significant time and resources each year to remove ice and snow from their paved surfaces to achieve a safe, accessible, and operational transportation network. An electrically conductive concrete (ECON) heated

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pavement system (HPS) has been shown to be a promising alternative to conventional snow removal operations using snowplows and deicing chemicals, which are time-consuming, labor-intensive, and environmentally unfriendly. In addition, they cause corrosion of reinforced concrete structures used in the construction of bridges, overpasses and other infrastructure objects. An ECON HPS utilizes the inherent electrical resistance of concrete to maintain the pavement surface above freezing and thus prevent snow and ice accumulation on the surface. Such a sustainable concrete pavement system improves infrastructure resiliency by allowing it to be safe, open, and accessible even during harsh winter storms. The performance evaluation showed promising results in producing snow- and ice-free pavement surfaces through several winter weather events [2].

Table 1. Electrically conductive concrete for multifunctional hybrid structures [compilation by authors].

№	Multifunction of Electrically Conductive Concrete (ECON)
1	Heated highways, runways of airfields, carriageways of bridges, pavements for deicing and snow melting
2	Electric heating devices of volumetric and film types for buildings and structures (floors, walls, floor panels, wall panels)
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 Structural Elements 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

Electric heating devices of volumetric and film types for buildings and structures (floors, walls, floor panels, wall panels). Heat transfer is thermal energy in transit due to a temperature difference [4]. Today, there are various heating systems for buildings and structures, which are based on various heat transfer mechanisms. It is believed that the most useful for man is radiant low-temperature radiant heating, since in the process of evolution it warmed with the help of solar heat, as well as from a fire. Floor heating systems provide heating where it is needed most, at floor level. The concept has been around for centuries, first used by the Romans who warmed air by an open fire which passed through voids below their dwellings. Today floor heating systems are far more advanced and are the 'next generation'. It is more cost effective - floor heating systems could save you between 15-30% on your heating bills as it reduces energy consumption. It is natural heat - floor heating systems heat the room by radiant heat therefore is more comfortable. It is healthier - radiant heat reduces the risk of allergies and the spread of germs and it prevents dust and air circulation and virtually eliminates dust mites in carpets. It looks great - a floor heating system is out of sight so there is no need to accommodate radiators, therefore offering more wall space. It is silent - a floor heating system does not use pipes so there are no moans and groans. It is flexible - with a floor heating system different rooms can be set to different temperatures [5].

Wall heating installations are a source of well-being. They provide heating through horizontal radiant heat instead of the ascending warm air provided by conventional heating systems. This avoids the permanent movement of air and the associated stirring up of dust. Rooms are evenly heated without different temperature zones in the heated rooms [6]. The advantages wall heating: heating and finished wall in one; ideal for timber-framed buildings, pre-fabricated houses, attics and renovation; heating system is large-surface, extremely energy-saving low temperature system.

Electromagnetic Pulse (EMP) Protection. Among the main civil sources of EMP are: geomagnetic disturbances or storms (e.g., solar flares); lightning discharges; electric transport (trams, trolleybuses, trains); power lines (city lighting, high voltage); electrical wiring (inside buildings, telecommunications); household electrical appliances; TV and radio stations (broadcasting antennas); satellite and cellular communications (broadcast antennas); personal computers. The main military sources of EMP are: nuclear weapon detonations; electronic warfare systems (EWS); radars [7].

The Electromagnetic Pulse (EMP) is mainly known as a product of a nuclear explosion, but sometimes it is known as a Nuclear Electromagnetic Pulse (NEMP). The purpose of Electromagnetic Pulse Protection (EMPP) is to prevent the electromagnetic pulses from high level nuclear weapons disrupting and destroying electronic equipment. The EMP Shielding of critical facilities is vital to protect a functioning command and control structure from EMP type attacks. The EMP Shield needs to be incorporated within the host building [8, 9].

Electrostatic discharge (ESD) Flooring System. Anti-static and an electrostatic discharge (ESD) flooring are widely used in many electronic manufacturing environments where static is present. Generally, you will need an ESD floor if you are manufacturing, repairing, servicing, handling or using equipment that is susceptible to damage from electrostatic discharge or if you deal with combustible materials. Some typical sectors include the manufacture of components for the electronics industry, aviation, automotive, IT, medical, oil and gas, printing, packaging, telecoms and even some food and beverage production environments.

In particular, chemical manufacturers and processors, as well as any businesses that may use flammable chemicals or materials in their operations, need to create static-free work environments to avoid igniting chemicals, fumes or even microscopic flammable particles. Additionally, hospitals and air-traffic control rooms should also take precautions to prevent static, especially if they rely on uninterrupted or guaranteed use of specialised electronic items [10].

Grounding switches to protect structures from stray currents and leakage currents. Running rails are used as the return path for the train current in most DC electrified rail transit systems. The resultant rail voltage causes stray current to return to the DC supply source via other paths, such as nearby metallic infrastructure. Stray current is the main cause of corrosion in metallic, reinforced concrete parts located in the railway proximity [11, 12].

Covering the surface of structures with an electrically conductive mortar or concrete connected to the soil grounding can be an effective method of protecting building structures from corrosion under the influence of stray and leakage currents.

Coating of Reinforced Concrete Structural Elements for the Electrochemical Anti-Corrosion Protection. In [13], the feasibility of a combined treatment of electrochemical chloride extraction (ECE) and cathodic protection (CP) in reinforced concrete structures using a conductive cement-graphite paste as anode has been studied. It has been proven that the prior application of an electrochemical chloride extraction treatment leads to greater durability of the anode. It has been shown that for reinforced concrete structures located in aggressive marine environments, the combination of electrochemical treatments, first ECE to reduce the chloride content and then CP to maintain passivation conditions, is capable of providing adequate protection conditions for the reinforcement, provided that the appropriate current density value is applied, according to the average content of chlorides present in the reinforced concrete structures.

The results of this work point out that it is possible to use a graphite–cement paste, overlaid on the surface of a reinforced concrete element, as the anode for successive treatments of electrochemical chloride extraction, to reduce the chloride content and then cathodic protection to maintain protective conditions for the steel reinforcement. It is possible to recover protective conditions against corrosion of steel reinforcement in concrete by applying a combined treatment of ECE followed by a continuous CP treatment.

Self-Sensing constructions for monitoring of technical condition. Recent advances in materials science and engineering have enabled the fabrication of structural materials with enhanced functionalities. One of those is self-sensing, where the material is engineered to transduce deformations or cracks and other defects and damage into measurable or observable changes. Such self-sensing capability can be leveraged to automate the nondestructive evaluation process of structural components, also known as structural health monitoring [14].

Thermal accumulators made of heat-resistant electrically conductive concrete. The ability of electrically conductive concrete to heat up when an electric current pass makes it possible to use it for the production of solid thermal batteries. Considering the high heating temperatures of concrete (up to 600°C), it must be heat-resistant. Concrete with liquid glass binder has these properties.

Effectively use electricity from renewable energy sources, in particular, solar energy produced by photovoltaic systems. These systems produce electricity during the day, which is converted into heat and used to heat rooms at night. Electricity from a centralized power supply system can be effectively used at night, when a reduced night electricity tariff is in effect. Night-time electricity consumption also helps balances the grid.

It is advisable to use heat accumulators for home heating, as well as in industrial greenhouses.

Electrified elements of heating and ventilation systems − air heaters. The practice of operating buildings shows that electrified heating and ventilation systems are relatively simple in technical design, are easily automated, and have minimal metal consumption. The use of heaters made of special alloys (nichrome) in electric heater installations, as well as closed heaters, tubular electric heaters, etc. significantly increase the cost of heating and ventilation equipment. In addition, currently used electric heater installations have high-temperature heaters, which leads to contamination of the heated air with combustion products of dust particles and to a deterioration of the microclimate of the heated room.

It is possible to develop a heater with a metal-free heater made of electrically conductive concrete. The heating elements are single-layer slabs of electrically conductive concrete, manufactured using well-known technology. The installation operates on current of industrial frequency at a voltage of 220-380V. The process of heating the air in the installation occurs as follows: the fan supplies air to the heater, then the air, washing the surface of the heating elements, is heated to a temperature of 60-80°C and supplied to the heating system.

The use of electrically conductive concrete as heating elements in heat generator installations significantly improves the technical and economic performance of electric generators, increases the degree of reliability of operation of heaters, their durability, and reduces manufacturing costs.

Batteries and supercapacitors of electrical energy. The large-scale implementation of renewable energy systems necessitates the development of energy storage solutions to effectively manage imbalances between energy supply and demand. Research conducted in recent years indicates the fundamental possibility of creating batteries and supercapacitors based on electrically conductive concrete. In this case, building structures (for example, slab foundations, reinforced concrete floors, wall structures) can be transformed into hybrid multifunctional structures capable of storing and releasing electrical energy from renewable sources. The availability, versatility, and scalability of these carbon-cement supercapacitors opens a horizon for the design of multifunctional structures that leverage high energy storage capacity, high-rate charge/discharge capabilities, and structural strength for sustainable residential and industrial applications ranging from energy autarkic shelters and self-charging roads for electric vehicles, to intermittent energy storage for wind turbines and tidal power stations [15].

2 The production of electrically conductive concrete

The production of electrically conductive concrete is based on the introduction of electrically conductive fillers (the so-called conductive phase) into its composition and its transformation into a non-metallic composite conductor. 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:

1. Direct contact of filler-conductor particles;
2. Emission of filler electrons through the gaps between particles (tunnel effect). The conduction mechanism can be either ionic or electronic in nature.

Ordinary concrete under certain temperature and humidity conditions has the ability to conduct electric current, but this property is not stable [3]. With seasonal fluctuations in temperature and humidity, the electrical resistance of ordinary concrete changes by 6-8 orders of magnitude. 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 103 Ohm·cm. Drying concrete leads to an increase in its resistance to 1011 Ohm·cm.

The binder used in concrete can be very different. Depending on its type, the following types of concrete are distinguished: polymer concrete, polymer cement concrete, concrete with a cement binder, concrete with a liquid glass binder. If we analyse them from the point of view of electrical, structural and economic efficiency [3], then we can say that the most suitable for electrical purposes 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.

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 role of carbon dispersions in the production of electrically conductive concrete is reduced to the formation of a conductive system due to direct contact of carbon-containing particles with each other. This effect is called electrical percolation (Fig. 1).

The conductive phase of electrically conductive concrete must have:

- 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.

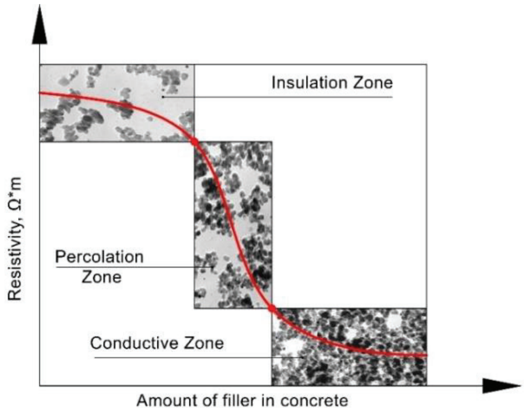


Fig. 1. Resistivity zones of electrically conductive concrete

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.

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 [7].

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

Carbon in natural and modified forms (Table 1…3) is widely used in industry [2].

Coke. Coal coke is a hard, grey, porous product with a high carbon content and few impurities, made by heating coal in the absence of air at temperatures of 950-1100°C without oxygen for 14-18 hours [16]. Electrical resistivity of coke beds depends of coke particle size [17, 19].

Carbon black. Carbon black (with subtypes acetylene black, channel black, furnace black, lamp black and thermal black) is a material produced by the incomplete combustion of coal tar, vegetable matter, or petroleum products, including fuel oil, fluid catalytic cracking tar, and ethylene cracking in a limited supply of air. Carbon black is a form of paracrystalline carbon that has a high surface-area-to-volume ratio, albeit lower than that of activated carbon. Insoluble in water [20].

Table 2. Formatting sections, subsections and subsubsections.

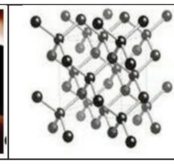
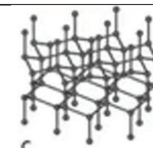
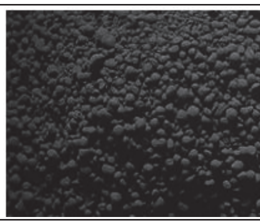
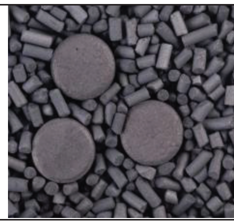
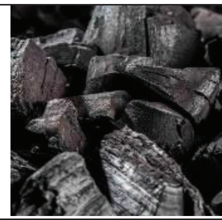
 	 	 
graphite	**diamond**	**lonsdale – diamond**

Table 3. Amorphous carbon modifications.

			
carbon black	**activated carbon**	**charcoal**	**coke**

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Graphite. Graphite is a mineral composed of stacked sheets of carbon atoms with a hexagonal crystal structure. It is the most stable form of pure carbon under standard conditions. Graphite is very soft, has a low specific gravity, is relatively non-reactive, and has high electrical and thermal conductivity [24].

Graphene. Graphene is an allotrope of carbon consisting of a single layer of atoms arranged in a hexagonal lattice nanostructure [3]. Single-layer graphene was explored theoretically in 1947. But only in 2004 Konstantin Novoselov and Andre Geim (University of Manchester, United Kingdom) successfully produced this material, graphene, and mapped its properties: incredibly thin but still incredibly strong, good heat and electrical conductivity, almost entirely transparent yet very dense. Despite its relatively young age, graphene and its modifications are used today in many industries, including construction [28].

Carbon Fibers. Carbon fibers or carbon fibres (alternatively CF, graphite fiber or graphite fibre) are fibers about 5 to 10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages: high stiffness, high tensile strength, high strength to weight ratio, high chemical resistance, high-temperature tolerance, and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, motorsports, and other competition sports. However, they are relatively expensive compared to similar fibers, such as glass fiber, basalt fibers, or plastic fibers [30].

The experimental results of measuring the resistivity of carbon materials are shown in Table 4. 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.

Measuring pure/intrinsic carbon material resistivity is relatively complicated. The results depend how completely the sample was compressed to reduce the void volume between aggregates and ultimately how the direct contact between aggregate surfaces is maximized.

There is, however, a limit to how low the intrinsic resistivity of conventionally produced carbon material can be. For example, for graphite powder this limit is set by the resistivity of the pure crystalline graphite measured parallel to the plane.

Table 4. Carbon materials and nanocarbon structures as fillers for creating electrically conductive composite materials.

Fillers	Resistivity, 10^5 Ω*m	Note	Reference
Coke	170-220 100-160	5-10 mm 15-20 mm	[17]
Needle Cokes	300-700		[18]
Coke breeze	70000 20000 6000 4000	0-2 mm 2-4 mm 4-6 mm 6-8 mm	[19]
Carbon Black	20-100 100-100000 40		[21] [22] [23]
Partcally Graphite Carbon Black			
Activated Anthracite			
Nanoporous bio-carbon			
Graphite	1 3 1 30 300	∥ plane ⊥ plane ∥ plane	[21] [17] [25] [25]
Graphite Powder	770		[26]
Fine Crystalline Graphite	1		[27]
Ultrafine graphite			
Thermally expanded graphite			
Nanographite			
Graphene			
High Purity Graphene (China)	70-100		[21]
Few layers graphene	5-10		[21]
Reduced Graphene Oxide	140		[21]
Graphene nanoplatelets			[26]
Carbon Nanotubes			
Fullerenes			
Carbon Fibers	9 200-2000	4-7 μm	[29] [30]

We proposed a method of testing the resistivity of electrically conductive carbon materials.

Testing of electrical conductivity of carbon nanomaterials. 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 220×12V or battery 12V; 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 1MPa; dynamometer; matrix (dielectric tube - propylene water pipe), with inner diameter of 32 mm, a working length of 250 mm, with electrically conductive punches; dial indicator with 0.01 mm division; thermocouple with temperature display (see Fig. 2).

Testing. The lower electrically conductive punch is inserted into the matrix. A sample of carbon material is loaded evenly into the matrix. An upper punch is inserted into a matrix, an internal diameter of 32 mm and a carbon material 250 mm high. The matrix with is placed under a press through dielectric spacers. A dial indicator is installed on the upper punch to measure the deformation (shortening) of the carbon filler. The thermocouple is installed into a matrix with a carbon material.

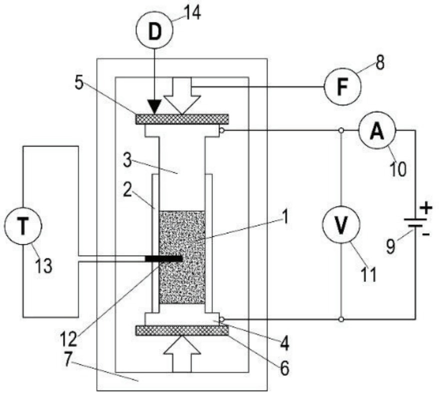
The controlled force providing a pressure on the material of 1 MPa (10 kgf/cm²) is equal to:

$$N = f \cdot A = f \cdot (\pi d^2 / 4) = 10 \cdot (3{,}1416 \cdot 3{,}22^2 / 4) = 80\ kgf, \qquad (1)$$

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

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. 2).



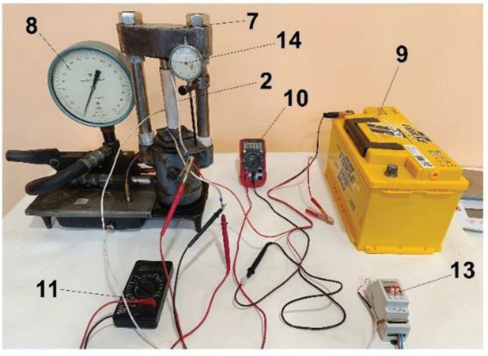


Fig. 2. Schema for testing the resistivity of electrically conductive fillers: 1 - conductive filler; 2 - matrix (dielectric pipe); 3, 4 - upper and lower conductive punch; 5, 6 - upper and lower dielectric gasket; 7 - press; 8 - force gauge of press; 9 - battery or transformer 220×12V; 10 - ammeter;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

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:

$$l = l_0 - \delta l \qquad (2)$$

where: l - is the length of the column of compacted carbon material, m; l_0 = 0.25 m - 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:

$$R = U / I \tag{3}$$

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.

The resistivity of carbon material is determined from the relationship:

$$R = p \cdot (l / A) \tag{4}$$

$$p = R \cdot (A / l) \tag{5}$$

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):

$$S = l / R \tag{6}$$

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

Specific conductivity of carbon material:

$$s = l / p \tag{7}$$

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.

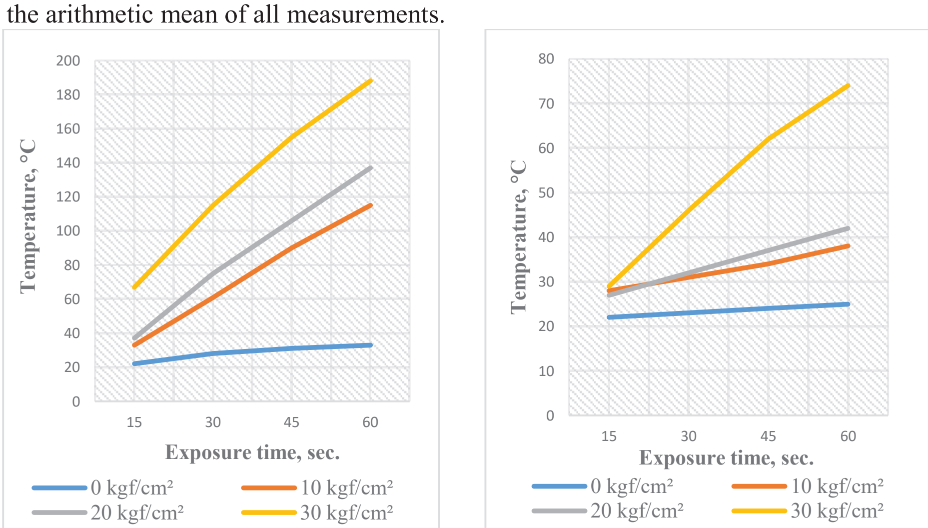


Fig. 3. Temperature of carbon fillers specimens depending exposure time under current under pressure

According to the developed method, the electrotechnical indicators of carbon fillers, such as coke breeze and carbon black, were studied. The current source is a battery. The working length of the tube is 100 mm, the inner diameter is 22 mm, the area is 3.8 cm² (0.00038 m²). The air temperature in the room is 20°C.The results of the research are shown in Table 5 and Figure 3.

Table 5. Testing results of carbon materials research.

Exposure time, sec	Temperature, °C	Current I, mA under pressure	Voltage U, V under pressure

	under pressure kgf/cm²				**kgf/cm²**				**kgf/cm²**			
	0	**10**	**20**	**30**	**0**	**10**	**20**	**30**	**0**	**10**	**20**	**30**
Coke Breeze												
15	22	33	37	67	5,2	66,5	111,2	138,4	12,9	11,0	9,6	8,6
30	28	61	75	115	5,5	66,5	112,2	138,5	12,8	10,9	9,4	8,5
45	31	90	106	155	5,6	66,9	113,3	138,6	12,8	10,9	9,4	8,4
60	33	115	137	188	5,6	67,8	113,9	138,7	12,8	10,8	9,3	8,2
midpoint					5.5	66,9	112,6	138,6	12,8	10,9	9,4	8,4
shortening, mm	0	6,7	11,5	18,6								
Carbon Black												
15	22	28	27	29	6,6	18,0	22,7	27,5	12,8	12,4	12,3	12,1
30	23	31	32	46	6,7	18,3	23,4	28,7	12,8	12,4	12,2	12,0
45	24	34	37	62	6,7	18,7	23,8	29,7	12,8	12,3	12,2	12,0
60	25	38	42	74	6,8	19,0	24,3	30,8	12,8	12,3	12,2	11,9
midpoint					6,7	18,5	23,5	29,2	12,8	12,4	12,2	12,0
shortening, mm	0	9,4	14,4	15,6								

4 Conclusions

Among smart concretes, electrically conductive concretes should be singled out for their functional properties. Systematization of electrically conductive concretes according to their new functional capabilities has been carried out. This type of concrete is obtained by adding conductive fillers to the concrete mixture. Among them, carbon materials are the most promising in terms of their properties. A generalization and systematization of carbon conductive materials as fillers for conductive concrete has been carried out. Due to the lack of standards for testing the electrical conductivity of both fillers and concrete, a method for testing the electrical conductivity of Carbon Nanomaterials (CNMs) as fillers for electrically conductive concrete is proposed. Approbation of the proposed method was carried out by determining the electrotechnical indicators of carbon fillers, such as coke breeze and carbon black.

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