The concrete modified by conductive mineral for electrode heating

Rustem Mukhametrahimov1[0000-0001-9999-9925], Albert Galautdinov1[0000-0001-9999-9925] and Ainur Garafiev1

1Kazan State University of Architecture and Engineering, Kazan, 420043, Russia
E-mail: muhametrahimov@mail.ru

Abstract. There are a lot of different methods of cold weather concreting. One of the weakly efficient methods of artificial concrete heating is electrode heating. The effectiveness of electrode concrete heating can be improved by means of conductive mineral addition to concrete mix that helps to support optimized resistivity of structure, reduce power costs and the period of development of strength in concrete. It is found that contraction of concrete mix modified by floured shungite in the quantity of 1% by mass of cement (5.18 ml) is lower than contraction of the initial unmodified concrete mix (8.15 ml) which shows its hydration processes slowing and demonstrates noneffect of shungite on concrete strength increase during electrode concrete heating. Concrete mix modifying by floured shungite helps to increase concrete temperature compared to initial mix by the value up to 8°C during the period of 0-20 hours of electrode heating, which leads to the structure’s strength development rate increase. Electric resistance decrease of the modified concrete mix that is observable during this process shows us improvement of the effectiveness of electrode concrete heating with shungite.

Keywords: cold weather concreting, electric curing of concrete, concretes, cements, conductive mineral, shungite, energy efficiency.

1 Introduction

In the current context of construction considerable increase of in-situ concreting volume during winter can be observed. In addition to this, appearance of new design and technology solutions of cast-in-place and precast frame buildings [1] at construction market resulted in stepping up the requirements to the quality of winter concreting. The key aspect of concreting during winter (at a temperature below +5 °C) consists in necessity of concrete ultimate strength development before the beginning of chemically inbound water crystallization processes [2, 3], which helps to exclude the appearance of internal stresses that disrupt concrete structure [4]. This calls for positive temperature of concrete mix for the period of ultimate strength development [5].

Different methods of winter concreting based on using antifreeze admixtures [6–10], on accelerating the rate of curing [11–17], on concrete curing by shuttering with heating elements [18], by concrete heating cables, by infrared rays and other methods [19–23] are widely known. Mixed methods of cold weather concreting are also can be used. The present article is concerned with [24] a theory about rationality of combined concrete heating method with the one of above mentioned methods (without heating) at temperatures below freezing, for example, antifreeze admixes application combining with concrete heating by the cable.

One of the weakly efficient methods of artificial concrete heating is electrode heating. The method of electrode heating of concrete mix in the structures is based on using heat generated during the concrete penetration of electric current [25]. Plate, strip, chord and rod electrodes have application for electrode heating of concrete structures. There are through electrode heating for structures with great thickness and structures with intricate shape (electrodes are placed in-structure) and peripheral electrode heating for structures of any massiveness (electrodes are placed at the space of structures) [26]. At the papers [27, 28] the effectiveness of electrode heating of the fiber reinforced composites is shown, at that, contact layer of fiber concrete makes a substantial contribution to average conductivity. Concrete mix conductivity increases proportional to fiber reinforcement percentage. The research
results can be useful in the choice of electrodes heating modes, and also in conductivity and coefficient of heat conductivity calculation of fiber reinforced concrete. This fact on some extent allows for the presumption about the effectiveness of conductive mineral introduction to the concrete mix during electrode heating [29–34]. The paper [35] shows the opportunity of electrothermal curing of precast concrete products. It is emphasized that the results of electrothermal concrete curing significantly depend on the rate and behavior of temperature gradients in the material volume and on kinetics of concrete strength development, at that, there is an opportunity of propitious temperature gradients magnitude control in the material during electrothermal curing by means of its varying parameters.

Temperature conditions of the heating are composed of three steps:
- rise of concrete temperature;
- isothermal warming: setpoint temperature regulation in concrete, for most cases during isothermal warming ultimate concrete strength is reached;
- concrete cooling in the structure: while cooling up to temperature of 0 °C, processes of structure formation and concrete strength development continue, what is considered during concrete casting of massive structure.

Thermal abuse of the heating can lead to concrete burning as a result of concrete overheat over 100 °C, to deficient concrete strength development, to local cracks formation et al. Oppositely, inadequate concrete heating or its deficiency leads to chemically gravitational water freezing, to internal stresses appearance that disrupts the concrete structure and lowers its strength. During the process specific marks of the “frost-bound” concrete are formed on the surface of the structures (Fig. 1).

Dry binders and aggregates forming part of concrete composition have high resistance, and liquid phase of concrete appears as electric conductor. Quantity and quality of liquid phase has a significant impact on resistivity variation of concrete. If we follow these changes then we may identify three basic stages:
- resistivity reduction;
- gradual stabilization of resistivity;
- progressive increase of resistivity.

According to these three stages there are the following stages of concrete formation:
- concrete clinker dissolution in water and liquid phase inundation by hydration products of concrete mixture;
- superaturation of liquid phase, colloidization and crystallization beginning of hydrated newgrowths;
- crystal matrix formation, structure compaction of cement stone and mechanical strength gain of the concrete.
During hydration of concrete mix and expulsion of some water on thermal curing of concrete, resistivity of concrete mixture and power costs increase can be observed correspondingly. During attainment of grade strength at the value of 40 % further thermal curing of concrete becomes difficult and concrete cannot harden fast enough in some cases [36]. In this vein, question of present interest is the question about improvement of the effectiveness of electrode heating, solution of which helps to improve quality of concrete structures and reduce power costs while winter concreting [26].

Based on literature data analysis we formulated working hypothesis that involves an opportunity to shore up optimized resistivity of structure, and, as consequence, to reduce power costs and duration of concrete ultimate strength development by means of floured conductive material shungite application to concrete mix. High conductivity of shungite rocks is due to specific pattern of carbon distribution in the volume of the rock. Apart from electrically conductive properties this material has high strength, density and chemical stability. Besides this, in [37–40] there was demonstrated that finishing materials and products modification by shungite rocks allow for giving them radioprotective properties.

2 Methods
For checking purposes of the suggested hypothesis we carried out experimental investigation about the influence of shungite content in concrete mixture on temperature variation, electric resistance and concrete strength during electrode heating. Hardening of concrete took place naturally at an ambient temperature of 15 °C below zero.

For experimental investigations we made two concrete mixes:

- mix No.1 – check mix (concrete graded B30 without shungite introduction);
- mix No.2 – modified mix (with shungite introduction in the quantity of 1 % by mass of cement).

The experiment was carried out for specimens with dimensions of 19x18x16.5 cm. Hardening of concrete took place under the influence of electrode heating. Compressive resistance of concrete was determined by GOST 10180-2012 “Concretes. Methods for strength determination using reference specimens” on compression testing machine IP-1000. During electrode heating electric resistance of concrete specimens was determined by means of multimeter, temperature – by means of mercury thermometers dipped into specimens’ body. Observation over experimental results was made during 115 hours one hour apart. In order to determine the effect of shungite on concrete temperature gradient during electrode heating kinetics of heat formation during cement hydration by means of measuring system “Termohron Revizor DS1921” with a temperature record frequency of one minute was studied. In order to determine the influence of shungite mineral on binder hydration Portland cement
contraction and prognosis of its activity by the measuring procedures MI 2486-98 and MI 2487-98 by means of contractional tube tester of cement activity “Cement-prognosis” were researched.

3 Results and Discussion
Temperature-time relationships of hydration of initial and modified binders are shown on Figure 2.

As you can see in Figure 2, shungite introduction in the quantity of 1 % by mass of cement do not lead to heat formation kinetics change of modified binder composition which is illustrative of its noneffect on heat formation processes during cement hydration.

Research results of cement contraction per eight hour show us the processes retardation of modified binder composition in comparison with the initial one. For example, the rate of initial composition contraction is 8.15 ml, contraction of composition modified by floured shungite – 5.18 ml.

Figure 2. Kinetics of heat formation during hydration of initial and modified binders.

Time of heating-temperature transformation dependence of concrete specimens of initial and modified compositions is shown in Figure 3.
Figure 3. Time of heating-temperature transformation dependence of concrete specimens of initial and modified compositions.

Experimental data analysis observed in Figure 3 shows temperature increase of modified concrete mix in comparison with the initial composition in the interval of 0-20 hours of electrode heating. In the interval of 20-115 hours of electrode heating temperatures of initial and modified concrete compositions do not differ substantively. Analysis and correlation of data represented in Figure 2 and Figure 3 show us that shungite introduction to concrete mix in the quantity of 1 % by mass of cement does not lead to substantial change of cement binder heat formation kinetics during its hydration, which is illustrative of temperature increase of concrete mix under the process of electrode heating by the aid of mineral electrically conductive properties. Dependences of time-resistance change of heat concrete samples are shown in Figure 4.

Figure 4. Time - resistance change curve of heat concrete samples.

At the received diagrams (Figure 4) it can be observed that resistance value of the concrete sample modified by shungite is less than the value of the initial composition. This fact shows us improvement of electrode heating effectiveness during shungite introduction to concrete mix. Apart from this, concrete specimen modified by shungite in the quantity of 1% by mass of cement during 115 hours got strength equal to 54.2 % while heating, the specimen without shungite – 45.2 % of design concrete grade B30. Experimental data analysis described in Figures 3 and 4 confirms the working hypothesis presented above.

Undertaken studies show positive influence of shungite on the effectiveness of concrete electrode heating. This is due to the decrease of electric resistance of modified concrete samples, temperature increase of modified concrete mix composition in comparison with initial composition at the beginning of electrode heating, what leads to intensification of hydration processes and to strength enhancement of samples.

4 Conclusions
1. Literature data analysis shows the effectiveness of conductive materials introduction to concrete mix that helps to improve effectiveness of concrete electrode heating.
2. It is found that shungite introduction in the quantity of 1 % by the mass of cement does not lead to substantial change of heat formation kinetics of cement binder. It shows that there is noneffect of minor amounts of shungite (1 %) on its hydration processes.
3. It is found that contraction of concrete mix modified by floured shungite in the quantity of 1 % by mass of cement (5.18 ml) is lower than contraction of the initial unmodified concrete mix (8.15 ml)
which shows its hydration processes slowing and demonstrates noneffect of shungite on concrete strength increase during electrode concrete heating.

4. It is found that concrete mix modifying by floured shungite in the quantity of 1 % by mass of cement helps to increase concrete temperature compared to initial mix by the value up to 8°C during the period of 0-20 hours of electrode heating. Additionally, electric resistance decrease of the modified concrete mix during electrode heating and increase of strength development rate can be observed. In that way, concrete specimen modified by shungite during 115 hours got strength equal to 54.2 %, the specimen without shungite – 45.2 % of design concrete grade B30.

5. Undertaken studies demonstrate us improvement of the effectiveness of concrete electrode heating with shungite and decrease of material cost for this process.

6. Experimental data confirm the working hypothesis that involves an opportunity to shore up optimized resistivity of structure during electrode heating and, as consequence, to reduce power costs and duration of concrete ultimate strength development by means of floured conductive material shungite application to concrete mix.

7. Analysis of influence of floured shungite content in concrete mixes on structure formation aspects and concrete properties under electrode heating and also the optimized heating modes of modified mixes determination represent the utmost interest for follow-up study.

Acknowledgements
This material is based upon work supported by Council for Grants of the President of the Russian Federation under Grant No. MK-2509.2018.8.

References
[1] Krylov B A 2012 Monolithic construction, its condition and prospects for improvement Stroitel'nye materialy, oborudovaniye, tekhnologii XXI veka 4 pp 35–38
[2] Golovnev S G 2013 Winter concreting: stages of formation and development Vestnik Volgogradskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta Ser. Stroitel'stvo i arkhitektura 2 pp 529–534
[3] Bofang Z 2014 Construction of Mass Concrete in Winter Thermal Stresses and Temperature Control of Mass Concrete
[4] Zhang G, Yu H, Li H and Yang, Y 2019 Experimental study of deformation of early age concrete suffering from frost damage Constr. Build. Mater. 215 pp 410–421 DOI: 10.1016/j.conbuildmat.2019.04.187
[5] Semenov K. V and Yu. G Barabanschikov 2014 Thermal crack resistance of massive concrete foundation slabs and its provision during winter construction period Stroitel'stvo unikal'nykh zdaniy i sooruzheniy pp 125–135.
[6] Karagol F, Demirboga R and Khushefati W H 2015 Behavior of fresh and hardened concretes with antifreeze admixtures in deep-freeze low temperatures and exterior winter conditions Constr. Build. Mater. 76 pp 388–395 DOI: 10.1016/j.conbuildmat.2014.12.011
[7] Mavlyuberdinov A R, Izotov V S and Nurgatin I I 2014 Studying the mechanisms of the influence of antifrosty additives on the properties of mortar mixtures Izvestiya Kazanskogo gosudarstvennogo arkhitектurno-stroitelnogo universiteta 2 pp 173–178
[8] Karagol F, Demirboga R and Khushefati W H 2015 Behavior of fresh and hardened concretes with antifreeze admixtures in deep-freeze low temperatures and exterior winter conditions Constr. Build. Mater. 76 pp 388–395 DOI: 10.1016/j.conbuildmat.2014.12.011
[9] Karagöl F, Demirboga R, Kaygusuz M A, Yadollahi M M, Polat R 2013 The influence of calcium nitrate as antifreeze admixture on the compressive strength of concrete exposed to low temperatures Cold Reg. Sci. Technol. 89 pp 30-35 DOI: 10.1016/j.coldregions.2013.02.001
[10] Nmai C K 1998 Cold weather concreting admixtures Cem. Conc. Compos. 240 117293
DOI: 10.1016/j.conbuildmat.2019.117893

[11] Pimenov S 2019 Special qualities of the formation of cement stone after hydromechanical activation of cement Nauchnyy zhurnal Stroit. i arkhitetuры. 54 pp 77–88.

[12] Pimenov S I 2019 Features of the structure formation of a cement stone after hydro-mechanochemical activation of cement Russ. J. Build. Constr. Archit. 49 pp 46–58.

[13] Khuzin A F, Gabidullin M G, Badertdinov I R, Rakhimov R Z, Abramov F P, Yumakulov R E Nizembaev A Sh and Perepelitsa Ye M 2013 Complex additives based on carbon nanotubes for high-strength accelerated concrete Izvestiya Kazanskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta 23 pp 221–226

[14] Khuzin A F, Gabidullin M G, Rakhimov R Z, Gabidullina A N and Stoyanov O V 2013 Acceleration of hardening of cement composites modified with carbon nanotube additives Vse materialy. Entsiklopedicheskii spravochnik 11 pp 32-36.

[15] Morozov N M, Stepanov S V and Khozin V G 2012 Galvanic sludge concrete hardening accelerator Inzhenerno-stroiteln'y zhurnal 34 pp 67–71

[16] Stepanov S, Morozov N, Morozova N, Ayupov D, Makarov D and Baishev D 2016 Efficiency of use of galvanic sludge in cement systems Procedia Engineering pp. 1112–1117 DOI: 10.1016/j.proeng.2016.11.827

[17] Liu Y, Tian W, Wang M, Qi B and Wang W 2020 Rapid strength formation of on-site carbon fiber reinforced high-performance concrete cured by ohmic heating Constr. Build. Mater. 244 118344 DOI: 10.1016/j.conbuildmat.2020.118344

[18] Mavlyuberdinov A R and Sungatullina G A 2015 Studying the processes of hardening concrete mix in thermoactive formwork Vestnik Tekhnologicheskogo universiteta 18 pp181–183.

[19] Brzhanov R T, Pikus G A and Traykova M 2018 Methods of increasing the initial strength of winter concrete IOP Conf. Ser. Mater. Sci. Eng. 451(1) 012083 DOI: 10.1088/1757-899X/451/1/012083

[20] Lazniewska-Piekarczyk B and Miera P 2019 Frost Resistance of Concrete from Innovative Air-Entraining Cements IOP Conf. Ser. Mater. Sci. Eng. 603(4) 042082 DOI: 10.1088/1757-899X/603/4/042082

[21] Khaliullin M I, Dimiyeva A I and Fayzrakhmanov I I 2019 The effect of additives of mechanically activated mineral fillers on the properties of composite gypsum binders Izvestiya Kazanskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta 50 pp 386–393

[22] Yermilova Ye Yu, Rakhimov R Z, Bulanov P Ye and Kamalova Z A 2018 The influence of the method of cooling a thermally activated mixture for composite cement on the composition of cement stone hydration products Izvestiya Kazanskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta 46 pp 283–290

[23] Pertsev V T, Perova N S, Ledenev A A and Zagoruyko T V 2019 The influence of nanostructuring components on the characteristics of cement stone and the properties of high-strength and heat-resistant concrete Izvestiya Kazanskogo gosudarstvennogo arkhitekturno-stroitelnogo universiteta 49 pp 163–171

[24] Ryazanova G N and Popova D M 2018 The use of a complex of heating and non-heating methods of curing concrete in winter conditions from the point of view of energy efficiency Nauka molodykh - budushchee Rossii sbornik nauchnykh statey 3-yy Mezhdunarodnyy nauchnyy konferentsii perspektivnykh razrabotok molodykh uchenykh pp 238–241

[25] Kobylina M A and Kaloshina S V 2017 Winter concreting technology Sovremennyye tehnologii v stroyitel'stve. Teoriya i praktika 2 pp 214–223

[26] Ivakhnikova A S 2019 Electrode heating of concrete WORLD SCIENCE: PROBLEMS AND INNOVATIONS sbornik statey XXXI Mezhdunarodnyy nauchno-praktichesky konferentsii (Penza) pp 68–70

[27] Matus Ye P 2019 Numerical simulation of electrical heating of disperse-reinforced concrete
with high conductivity fibers \textit{Vestnik yevrazijskoy nauki} \textbf{2} pp 1–9

[28] Belli, A, Mobili, A, Bellezze T and Tittarelli F 2020 Commercial and recycled carbon/steel fibers for fiber-reinforced cement mortars with high electrical conductivity \textit{Cem. Concr. Compos.} \textbf{109} 103569 DOI: 10.1016/j.cemconcomp.2020.103569

[29] Armoosh S R and Oltulu M 2019 Effect of Different Micro Metal Powders on the Electrical Resistivity of Cementitious Composites \textit{IOP Conf. Ser. Mater. Sci. Eng.} \textbf{471}(3) 032075 DOI: 10.1088/1757-899X/471/3/032075

[30] Wang H, Yang J, Liao H and Chen X 2016 Electrical and mechanical properties of asphalt concrete containing conductive fibers and fillers \textit{Constr. Build. Mater.} \textbf{122} pp 184-190 DOI: 10.1016/j.conbuildmat.2016.06.063

[31] El-Dieb A S, El-Ghareeb M A, Abdel-Rahman M A H, Nasr E S A 2018 Multifunctional electrically conductive concrete using different fillers \textit{J. Build. Eng.} \textbf{15} p 61-69 DOI: 10.1016/j.jobe.2017.10.012

[32] Faneca G, Segura I, Torrents J.M, and Aguado A 2018 Development of conductive cementitious materials using recycled carbon fibres \textit{Cem. Concr. Compos.} \textbf{92} p 135-144 DOI: 10.1016/j.cemconcomp.2018.06.009

[33] Fulham-Lebrasseur R, Sorelli L and Conciatori D 2020 Development of electrically conductive concrete and mortars with hybrid conductive inclusions \textit{Constr. Build. Mater.} \textbf{237} 117470 DOI: 10.1016/j.conbuildmat.2019.117470

[34] Garcia Á, Schlangen E, van de Ven M and Liu Q 2009 Electrical conductivity of asphalt mortar containing conductive fibers and fillers \textit{Constr. Build. Mater.} \textbf{23}(10) pp 3175-81 DOI: 10.1016/j.conbuildmat.2009.06.014

[35] Fedosov S V, Bobylev V I and Sokolov A M 2011 Temperature characteristics of electrothermal treatment of concrete by electrode heating \textit{Stroitel’nye materialy} pp 56–59

[36] Bogatyreva T V and Mar’yasov R S 2010 Scientific substantiation of energy-saving technology for winter concreting of bored piles \textit{Izvestiya vysshikh uchebnykh zavedeniy. Stroitel’stvo} pp 38–51

[37] Kupriyanov V N, Morozov O G, Nasybullin A R and Shafigullin R I 2016 To the study of attenuation of electromagnetic waves by building envelopes \textit{Privolzhskiy nauchnyy zhurnal} \textbf{1} pp 38–45

[38] Mukhametraikhimov R K, Shafigullin R I and Kupriyanov V N 2017 Development of radioprotective shungite containing gypsum-fiber cladding sheets \textit{Izv. Kazan. Gos. arkitekturo-stroitel’nogo Univ.} \textbf{41} pp 224–231

[39] Chung D D L 2000 Materials for electromagnetic interference shielding. \textit{J. Mater. Eng. Perform.} \textbf{9}(3) pp 350-354 DOI: 10.1361/105994900770346042

[40] Terukov E I, Babaev A A, Tkachev A G and Zhilina D V 2018 Radio-Wave Absorbing Properties of Polymer Composites on the Basis of Shungite and Carbon Nanomaterial Taunit-M. \textit{Tech. Phys.} \textbf{63}(7) pp 1044-48 DOI: 10.1134/S1063784218070289