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Carbon-Containing Heat-Insulating Concrete from Waste of Kovdor GOK

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Abstract: *The article is devoted to the development of unshaped materials from industrial waste. Refractory concrete is the most popular, it consists from filler, binder and additives, which is hardened under normal conditions and has limited shrinkage at application temperature. The lightweight carbon-containing concrete was obtained from the waste of the Kovdor mining and processing plant with magnesium or ammonium-magnesium phosphate cements. The use of phosphate binders for the manufacture of these materials greatly simplifies the technology, eliminates high-temperature firing, and reduces the cost. The non-fired concretes make it possible to speed up the construction and repair of thermal units, to adopt fundamentally new technical solutions in the development of furnace designs and leads to an increase in their operational characteristics.*

As a result of the research, the grain composition of the charge was selected, the ratio of filler and binder was found to improve the structural properties of concrete. Experimental dependences of density, compressive strength and change in volume after heat treatment of carbon-containing forsterite concrete on the number of granules and fine fraction of the briquette in the charge, the type of phosphate binder and additives to it are revealed. Concretes are following characteristics: bulk density 910-1700 kg / m3, compressive strength up to 10 MPa, change of volume after heat treatment at 450°C 2-4%.

Recovering the waste of Kovdor GOK will lead to the elimination of sources of environmental pollution and the restoration of lands occupied by waste.

Keywords: *Forsterite, Carbon, Unshaped Material, Magnesium Phosphate Cement, Ammonium Magnesium Phosphate binders, Heat-insulating Concrete*

1. Introduction

Light heat-resistant concretes on porous aggregates have an average density in the range of 400-1200 kg/m3, compressive strength from 2.5 to 15 MPa, heat resistance of 25-35 air heat cycles, application temperature of 1000-1600°C. These concretes can be used as efficient thermal insulation of thermal units instead of expensive ultralight products.The concretes are used monolithically and as separate prefabricated blocks [1].

The aim of this work is to produce light carbon-containing concrete from waste from the Kovdor mining and processing plant on magnesium phosphate and magnesium ammonium phosphate binders.

In the previous work, the possibility of obtaining refractory concretes from the waste of Kovdor GOK on a magnesium phosphate binder was considered, the processes occurring in the filler-binder system were analyzed in sufficient detail [2].

There are a number of studies devoted on the development of technologies using MgO and ammonium phosphates, which interact less actively than binders on base of phosphoric acid. There are a number of studies on the development of technologies using MgO and ammonium phosphates, which interact less actively than phosphoric acid binders. Limes and Ponzani have taken a major step towards developing modern magnesium phosphate systems. They invented refractory cement, which can be pulverized on the sides of the oven. It is resistant to both high and low temperatures. Limes and Ponzani proposed using a mixture of liquid ammonium ortho-, pyro-, and polyphosphates with dead-burnt MgO, thus producing a cold-set spray composition, because MgO mixed with phosphoric acid reacts too rapidly for spraying [3].

Stierli et al. suggested adding boron compounds ($Na_2B_4O_7 \bullet 10H_2O$) to control the reaction rate and provide a more comfortable setting time [4].

The publications of Sugama and Kukacka provide data on the testing of cements made from MgO and diammonium phosphate $(NH_4)_2HPO_4$, as well as magnesium oxide and ammonium polyphosphate. They stated that main products formed are struvite ($MgNH_4PO_4 \cdot 6H_2O$) and $Mg_3(PO4)_2 \cdot 4H_2O$, as well as small amounts of newberyite ($MgHPO_4 \cdot 3H_2O$) and $Mg(OH)_2$ [5, 6].

Abdelrazig and Sharp disagreed with these findings. Theywere argued that the reaction of MgO and monoammonium phosphate $NH_4H_2PO_4$ produces dittmarite ($MgNH_4PO_4 \cdot H_2O$), while adding sodium tripolyphosphate as a retarder produces struvite and shertelite ($Mg(NH_4)_2(HPO_4)_2 \cdot 4H_2O$) [7].

Popovics et al. have determined that dittmarite is the main product if setting is fast (i.e. without a retarder), while struvite is the main product if setting is slow [8].

In addition, the formation of small amounts of dittmarite in the magnesium phosphate system is due to the presence of insufficient water during the hydration or dehydration of the struvite due to the heating of the cement according to the exothermic reaction, with the temperature rising to 80°C [9].

Although numerous studies have been undertaken on this topic, comparisons of struvite based cement systems are difficult due to large differences in the use of retarders, magnesium/phosphate ratios and the proportions of water. An increase in the water content in the mixture reduces its compressive and bending strength [10–12].

Bensted reports that the addition of water above 20% by weight causes the magnesium ammonium phosphates to "break down", i.e. the cement remains in suspension and does not set functionally [13].

The mechanism of action of ammonium phosphates is still poorly understood. Neiman and Sarma believe that this is an end-to-end process involving the dissolution of ammonium phosphates and parts of MgO. They observed the presence of an amorphous phase during the first hours surrounding the excess MgO and filler. Colloidal hydrated particles form around struvite cores ($NH_4MgPO_4 \cdot 6H_2O$). These particles then initiate the setting phenomenon through a gel-like interaction. This initial reaction occurs in an aqueous medium involving several $NH_4H_2PO_4$ molecules with an equivalent number of MgO molecules in solution, resulting in the formation of a multimolecular framework of $NH_4MgPO_4 \cdot 6H_2O$, which is schematically represented as $(NH_4MgPO_4 \cdot 6H_2O)_n$. At a low value of n, such as n = 3, it forms a chain ring -O - P - O - Mg - O - P - and the ring is surrounded by hydrogen-rich species such as H_2O and NH_4. These groups form hydrogen bonds with excess water, NH4H2PO4 and other structures $(NH_4MgPO_4 \cdot 6H_2O)_n$, resulting in the formation of particles of a colloidal type. These particles then coagulate around the excess MgO and SiO_2 filler particles, initiating a setting reaction. Over longer periods of time, they observed the crystalline reaction product, which was mainly struvite [14].

Recently, much attention has been paid to magnesium-potassium phosphates as a binder for concretes for various purposes. Magnesium phosphate cement is made by mixing MgO with KH_2PO_4 and/or borax powder. The principles for selecting components for optimizing the physical and chemical properties of cements are proposed. It is emphasized that the compressive strength depends on the molar ratio of phosphate to MgO[15–19].

2. Material and Methods of Research

2.1. Raw Materials

According to the "genesis" and the form of accumulation, technological waste from mining can be divided into two groups - "wet" and "dry". At Kovdor GOK, the first group includes fine heavily watered sands containing residual concentrations of the main useful components, as well as valuable or potentially valuable impurities not recovered in the production process for technological, economic or market reasons (for example, the mineral forsterite with up to 50% MgO). The second group includes dumps-warehouses of poor and off-balance ores of developed deposits.

The chemical composition of forsterite concentrate from processing waste is as follows, %:MgO – 43 - 48; SiO_2 – 33 - 39; FeO – 4.4 - 5.3; Fe_2O_3 – 0.8 - 5.9; CaO – 0.6 - 2.4; loss on calcination – 0.1-1.5.Forsterite of the Kovdor iron ore deposit contains, as a rule, from 3 to 8 molecular percent Fe_2SiO_4.

The classification by grain size of forsterite concentrate is as follows, %:(>0.2 mm) - 1, (-0.2+0.16 mm) - 7, (-0.16+0.1 mm) - 48, (-0.1+0.063mm) - 25, (-0.0630+0.05 mm) - 5, (< 0.05 mm) - 14.

Basic magnesium carbonate $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$was used to obtain magnesium phosphate cement,with density 1.491-1.556 g/cm^3.

2.2. Methods

X-ray phase analysis of the obtained lightweight concretes was carried out on a DRF-2 diffractometer (CuKα-radiation). Fractographic studies were performed on a scanning electron microscope using SEM LEO 420.

Technical requirements for lightweight concrete are presented in accordance standards[1, 20]. Compressive strength is determined according to GOST 10180-2012 [21]. Density is determined according to GOST 12730.1-2020[22].

Experimental dependences of density, compressive strength and change in volume after heat treatment of carbon-containing forsterite concrete on the number of granules and fine fraction of the briquette in the charge, the type of phosphate binder and additives to it are revealed.

2.3. Preparation of Concrete Samples

In the charge for concrete carbon containing granules, briquette from forsterite and phosphate binders are used.

Formation of granules from mixtures of electrode graphite with finely ground powdered forsterite concentrate involves obtaining a more favorable particle shape, which will ensure high rheological properties of lightweight concrete. The composition of the charge for granules, wt.%: 50 - forsterite concentrate, 25 - electrode graphite, 25 - caustic magnesite.

Obtaining of granules: the composition is subjected to grinding in an IV 1 vibrating grinder, to obtain a fraction < 0.063 mm, $MgCl_2 \cdot 6H2O$ (density 1.259 g/cm3) is added, rubbed through a 1 mm sieve, powdered with aluminum, dried, fired at 1000°C in a reducing environment.

In addition to carbon-containing forsterite granules, the composition of the charge for lightweight concrete includes a briquette.

Briquette composition, %: 50 - forsterite concentrate < 0.2 mm and 15 - forsterite concentrate < 0.063 mm, 35 - broken magnesite products < 0.2 mm.

Technological scheme for obtaining a briquette: a charge of a certain composition mixed, a binder (polyvinyl alcohol) is introduced, pressed under a pressure of 50-70 MPa, dried in natural conditions during the day. Then it is fired at a temperature of 1400. The resulting briquette crushed to obtain fractions <3 mm, a part is subjected to grinding in an IV 1 vibration grinder to obtain a fraction < 0.063 mm.

The classification by grain size of crushed briquette, %: (-3+2.5 mm) - 1, (-2.5+1.6 mm) - 14, (-1.6+1 mm) - 9, (-1+0.63 mm) - 7, (- 0.63+0.4 mm) – 6, (-0.4+0.315 mm) – 10, (-0.315+0.2 mm) – 15, (-0.2+0.16 mm) – 8, (-0.16+0.063 mm) – 14, (< 0.063 mm) - 16.

The most promising structural and heat-insulating concretes are porous materials on phosphate binders. Magnesium phosphate obtained from basic magnesium carbonate $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$ according to the reaction:

$$4MgCO_3 \cdot Mg(OH)_2 \cdot 4H_2O + 10H_3PO_4 \rightarrow 5[Mg(H_2PO_4)_2 \cdot 2H2O] + 4CO_2$$

To obtain lightweight concrete, mixtures of granules and briquette with magnesium phosphate binder is poured into detachable metal molds 45 mm high. They are kept for 1 day, then the molds are disassembled and the samples are kept in air for another 6 days. Next, the samples are heat-treated at 450°C with exposure for 2 h at the maximum temperature.

2.4. Testing of Concrete Samples

The samples were tested for compressive strengths, density, changes in the volume after temperature treatment. Compressive strengths were calculated for cubic specimens from the ratio of the applied load to their cross-sectional area [21]. The density was determined from the weight of samples to volume ratio [22]. The change in volume is expressed as the difference between the volumes before and after heat treatment to the initial volume of the samples and calculated as a percentage [23].

3. Results and Discussion

3.1 Investigation of the Process Occurring During Sample Sintering

Analysis of X-ray phase analysis data of lightweight concretes of various compositions shows the presence of forsterite, periclase, newberyite $MgHPO_4 \cdot 3H_2O$.

The phase composition of the samples was studied depending on the heat treatment of the mixture. Newberyite at 150°C passed into hydroorthophosphate monohydrate $MgHPO_4 \cdot H_2O$. At 200°C, $MgHPO_4 \cdot H2O$ was transformed into $MgH_2P_2O_7$ dihydropyrophosphate. After 400°C, the lines of tetrametaphosphate $Mg_2P_4O_{12}$ are marked on the X-ray diffraction pattern, from 700°C orthophosphate $Mg_3(PO_4)_2$.

Figures 1-4 show the surface structure of samples with different contents of carbon-containing forsterite granules. Needle aggregates of newberyite are noted, which play the role of a binder to ensure strength.

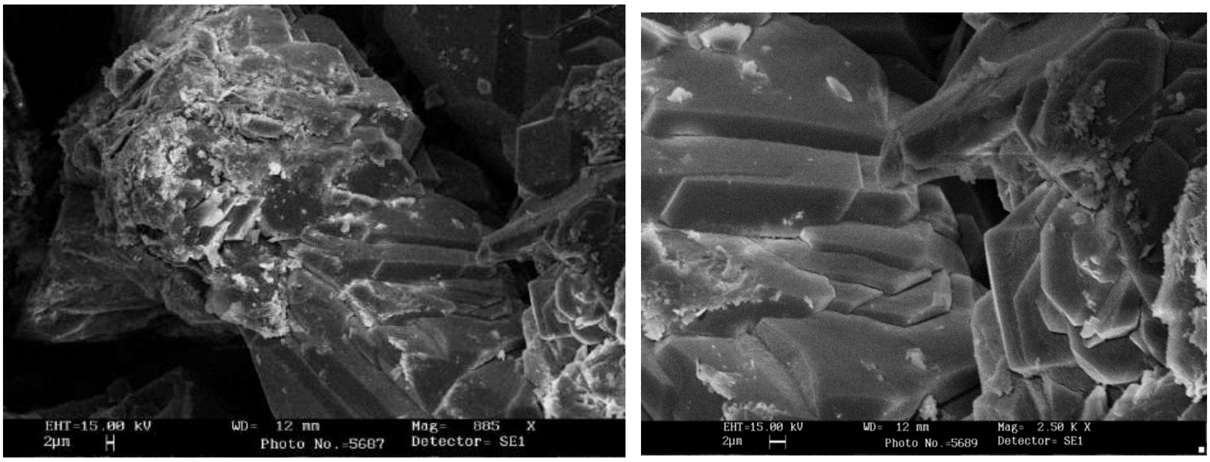


Figure 1 - SEM micrograph of the surface structure of samples from the charge (80% granules + 20% briquette < 0.063 mm) on the MPC / LST = 70/30 binder (analyst, Ph.D. Semushin V.V.)

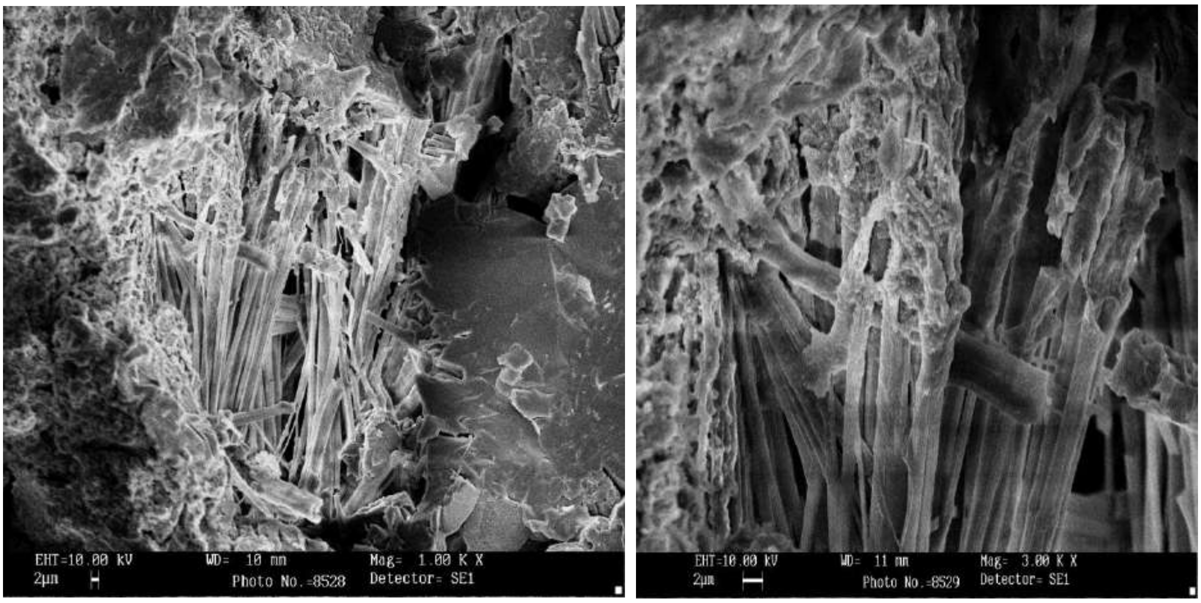


Figure 2 - SEM-micrograph of the surface structure of samples from the mixture (70% granules + 30% briquette < 0.063 mm) on the MPC / LST = 60/40 binder (analyst, Ph.D. Semushin V.V.)

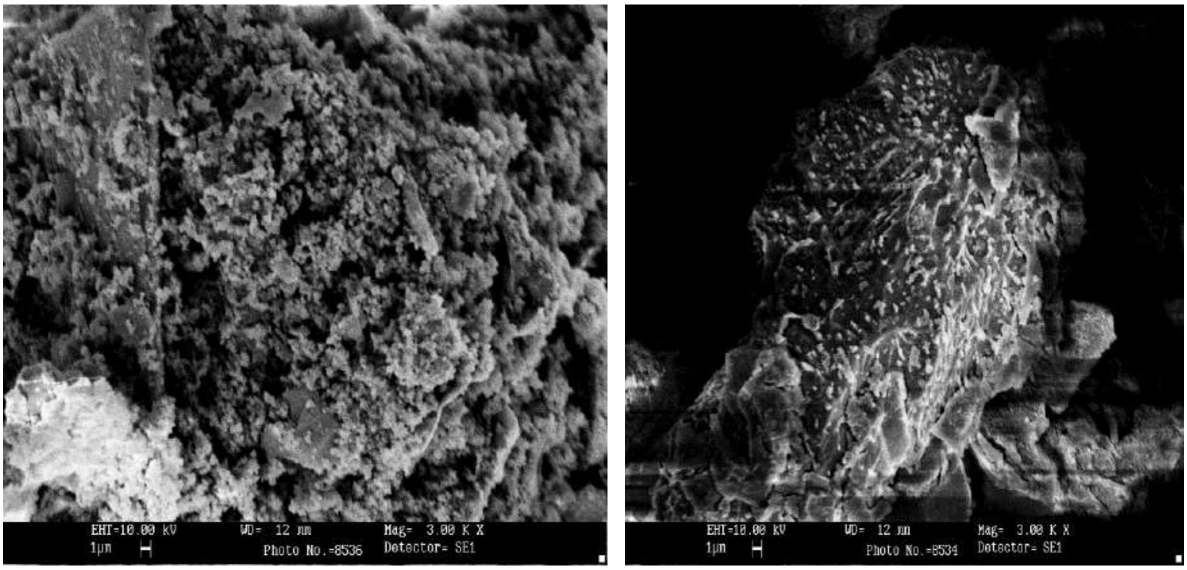


Figure 3 - SEM-micrograph of the surface structure of samples from the charge (60% granules + 40% briquette < 0.063 mm) on the MPC/LST=50/50 binder (analyst, Ph.D. Semushin V.V.)

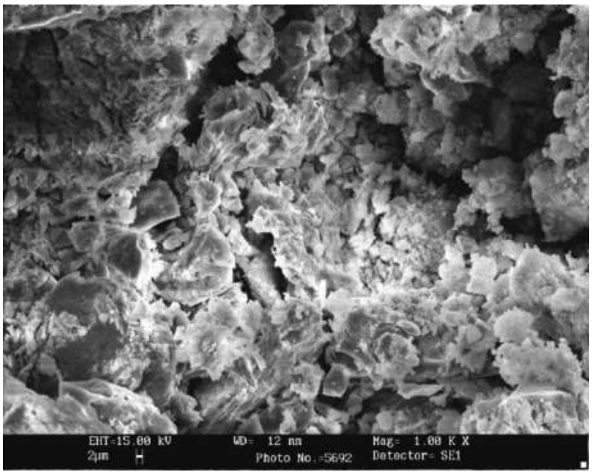


Figure 4 - SEM micrograph of the surface structure of samples from the charge (40% granules + 60% briquette < 0.063 mm) on the MPC/LST=50/50 binder (analyst, Ph.D. Semushin V.V.)

Newberyite is present in the form of tabular crystals, which initially help to hold the components of the mixture together.

According to X-ray diffraction data, as a result of the interaction of monoammonium phosphate $NH_4H_2PO_4$ with a briquette from forsterite concentrate, struvite $MgNH_4PO_4 \cdot 6H_2O$, dittmarite $MgNH_4PO_4 \cdot H_2O$, and bobbierite $Mg_3(PO_4)_2 \cdot 8H_2O$ were formed, and in the case of diammonium phosphate $(NH_4)_2HPO_4$, struvite and ditmarite were formed.

$$MgO + NH_4H_2PO_4 + 5H_2O \rightarrow MgNH_4PO_4 \cdot 6H_2O$$

$$MgO + NH_4H_2PO_4 \rightarrow MgNH_4PO_4 \cdot H_2O + H_2O$$

$$3MgO + 2NH_4H_2PO_4 + 5H_2O \rightarrow Mg_3(PO_4)_2 \cdot 8H_2O + 2NH_3$$

$$MgO + (NH_4)_2HPO_4 + 5H_2O \rightarrow MgNH_4PO_4 \cdot 6H_2O + NH_3$$

$$MgO + (NH_4)_2HPO_4 \rightarrow MgNH_4PO_4 \cdot H_2O + NH_3$$

Struvite is the binding phase. The presence of dittmarite in the samples may be due to the presence of an insufficient amount of water during the hydration or dehydration of the struvite due to the heating of the cement due to the exothermic reaction during the introduction of salt.

Figure 5 shows the surface structure of the material from a forsterite briquette less than 0.063 mm, on a binder $(NH4)_2HPO_4$. Struviteneoplasmswerenoted.

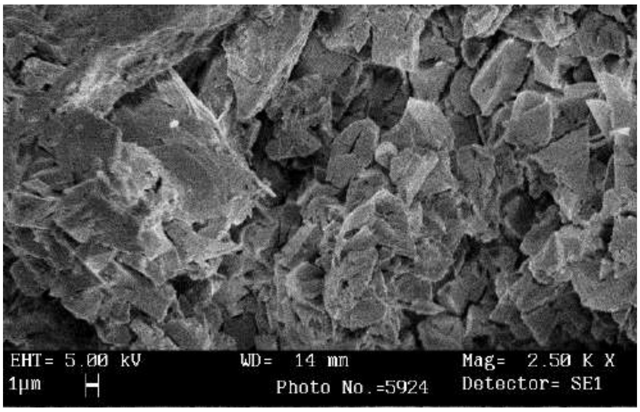


Figure 5 - SEM micrograph of the surface structure of samples on a diammonium phosphate binder (analyst, Ph.D. Semushin V.V.)

3.2 Compressive Strengths and Bulk Density of Samples on Magnesium Phosphate Binders

Graphs of changes compressive strength and density of concretes dependence of ratio briquettes/granules for magnesium phosphate binder (MPC) are presented in the Figures 6, 7.

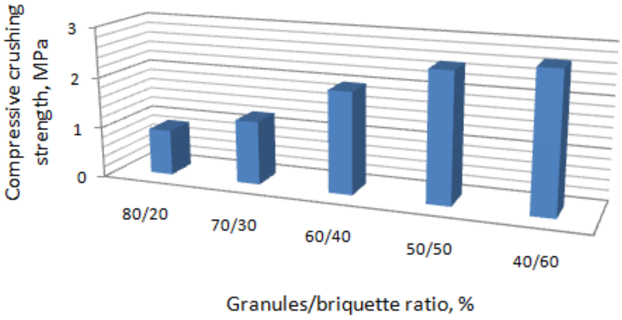


Figure 6 - Influence of the ratio of granules / briquette on the strength of lightweight concrete on a magnesium phosphate binder (after 28 days of hardening)

With an increase in the amount of briquette in the charge, the strength of lightweight concrete increases, the highest strength is in the sample from the charge (40% granules + 60% briquette < 0.063 mm).

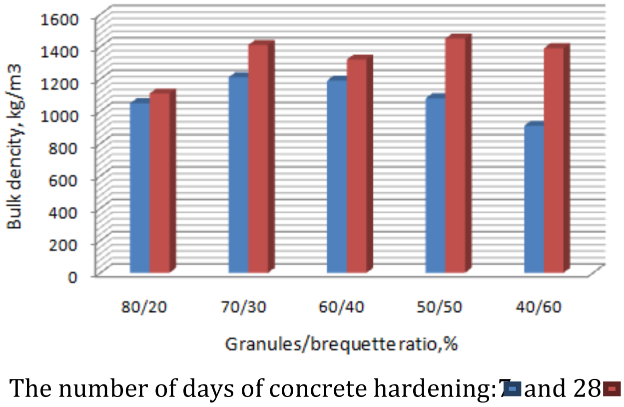


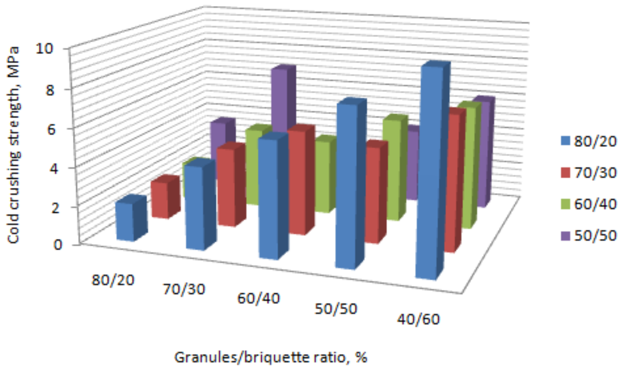
Figure 7 - Influence of the granule / briquette ratio on the density of lightweight concrete on a magnesium phosphate binder

Compressive strength increases with increasing content of the briquette, but the reaction with magnesium phosphate obtained from basic magnesium carbonate proceeds quite rapidly, so it was decided to conduct tests with a moderator, which was chosen as lignosulfonate (LST). The combined binder of MPC and lignosulfonate ensures slower interaction of the components with gradual release of heat. The MPC/LST ratio was as follows: 80/20, 70/30, 60/40, 50/50. The properties of samples based on carbon-containing granules and briquette<0.063 mm are shown in Table 1. All samples after 28 days of curing.

Table 1 - Properties of concretes on a combined binder

№ of samples	MPC/LST ratio	Density, kg/m^3	Compressive strengths, MPa
80% granules +20%briquette<0.063 мм			
1.1	80/20	1230	2
2.1	70/30	1200	2
3.1	60/40	1190	2
4.1	50/50	1250	3.5
70% granules + 30%briquette<0.063 мм			
5.1	80/20	1410	4.3
6.1	70/30	1440	4.2
7.1	60/40	1420	4.3
8.1	50/50	1460	7
60% granules + 40%briquette<0.063 мм			
9.1	80/20	1540	6
10.1	70/30	1380	5.5
11.1	60/40	1440	4
12.1	50/50	1420	3
50% granules + 50% briquette <0.063 мм			
13.1	80/20	1540	8
14.1	70/30	1470	5
15.1	60/40	1480	5.5
16.1	50/50	1390	4
40% granules + 60% briquette<0.063 мм			
17.1	80/20	1560	10
18.1	70/30	1500	7
19.1	60/40	1490	6.5
20.1	50/50	1480	6

Figure 8 shows the dependence of the strength indicators of lightweight concrete on the ratio of granules and briquettes in the charge, as well as the composition of the combined binder.



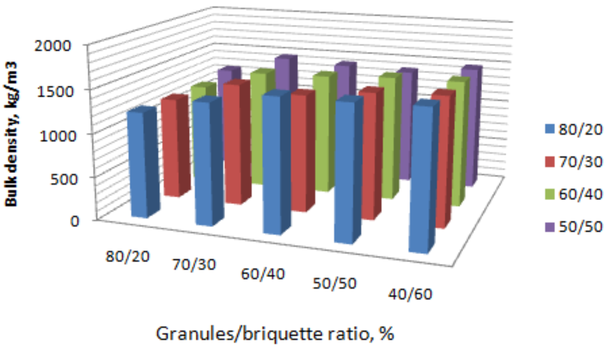
In the legend, the MPC:LST ratio

Figure 8 - Influence of the ratio of granules / briquette and MPC / LST on the strength of lightweight concrete on a combined binder

It is noted that when the briquette content in the charge is 20-30%, the strength index for samples with a combined binder MPC:LST = 50:50 increases. At the same time, when the content of a briquette in the charge is 40-60%, the strength index for samples with a combined binder MPC:LST = 80:20 increases. With a decrease in the content of MPC in the binder, the strength values decrease.

The introduction of lignosulfonate into the binder had a positive effect on strength, it increased. The maximum strength (10 MPa) is possessed by a sample from a mixture (40% granules + 60% briquette <0.063 mm) at a ratio of MPC/LST=80/20.

Figure 9 shows the dependence of density indicators on the ratio of granules and briquettes in the charge.



In the legend, the MPC:LST ratio

Figure 9 - Influence of the ratio of granules / briquette and MPC / LST on the density of lightweight concrete on a combined binder

Density after firing at 450°C decreases and shrinkage of 2.7–4.1% occurs.

3.3 Compressive Strengths of Samples on Ammonium Phosphate Binders

Further, the following were tried out as a binder, monoammonium phosphate $NH_4H_2PO_4$ and diammonium phosphate (NH4)2HPO4 were tested as a binder.

Preliminary study was carried out on the ability to harden the components of the charge and their compositions with the introduction of ammonium phosphates, at a ratio of charge: binder = 3:1. Strength data are given in the Table 2.

Table 2 - Strength of samples on a magnesium ammonium phosphate binder

Charge	Compressive strengths, MPa	
	$(NH_4)_2HPO_4$	$NH_4H_2PO_4$
Forsterite briquette	14	13
Granules	2	2
Granules + Forsterite briquette	5	5
causticmagnesite	1	1
Granules +caustic magnesite	crumbles	crumbles
Forsterite green	crumbles	2

To obtain lightweight concrete, a mixture of carbon-containing granules, a briquette and an ammonium phosphate salt is thoroughly mixed, poured with water or magnesium phosphate solution, and placed in detachable metal molds 40x40 mm. The samples are kept for 1 day, then molds are disassembled and further drying takes place in air for 6 days.

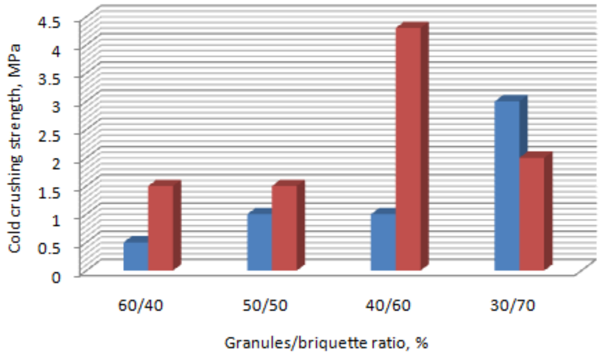
Table 3 shows the density and strength of concrete when using ammonium-magnesium phosphates and solution (water or magnesium phosphate).

Table 3 - Properties of carbon-containing lightweight concretes on ammonium phosphate binders

№ of samples	Binders	Density, kg/m³	Compressive strengths, MPa
60% granules+ 40% briquette<0.063 мм			
1v 1 mp 2v	$(NH_4)_2HPO_4$ $(NH_4)_2HPO_4$ $NH_4H_2PO_4$	1500 830 930	0.5 2.5 1.5
50% granules+ 50% briquette<0.063 мм			
3v 3 mp 4v 4 mp	$(NH_4)_2HPO_4$ $(NH_4)_2HPO_4$ $NH_4H_2PO_4$ $NH_4H_2PO_4$	1620 1020 970 1620	1 4 1.5 7
40% granules+ 60% briquette<0.063 мм			
5v 6v	$(NH_4)_2HPO_4$ $NH_4H_2PO_4$	1500 1210	1 4
30% granules+ 70% briquette<0.063 мм			
7v 8v	$(NH_4)_2HPO_4$ $NH_4H_2PO_4$	1700 1060	3 2

Solution: v–H_2O, mp-magnesium phosphate

Samples with compressive strengths3-4 MPa (7v, Table 3) on $(NH_4)_2HPO_4$ from the charge (30% granules + 70% briquette <0.063 mm) and the sample (6v, Table 3) on $NH_4H_2PO_4$ from the charge (40% granules + 60% briquette <0.063 mm) with viscosifier water were obtained. It was found that when using a solution of magnesium phosphate as a dry mix of the components of the charge and diammonium phosphate, the cold crushing strengths of the samples increases (3 mp and 1 mp, Table 3). The dependence of the strength of the studied structural and heat-insulating concrete on the ratio of granules / briquette, the type of ammonium phosphate and the solution is presented in Figure 10.



🟦 - diammonium phosphate, 🟥 -monoammonium phosphate

Figure 10 - Influence of the ratio of granules / briquette on the compressive strength of lightweight concrete on ammonium phosphate binders

In general, it can be said that carbon-containing lightweight concretes showed greater strength on ammonium phosphate binders than on MPC, but less than on a combined binder.

3.4 Discussion

The low wet ability and good thermal conductivity of graphite significantly increase the corrosion and thermal resistance of concretes, which are promising unshaped materials. The paper investigates the characteristics of carbon-containing concretes based on magnesium phosphate cements, in which waste from processing production and spent coal rods are used.

Transformations during heating of materials with magnesium and magnesium ammonium phosphate binders have been studied by many scientists in great detail and by various methods. The main attention was paid to the identification of neoplasms and the determination of the temperature range of their stability. The practical importance of this information is related to the choice of heating mode and the identification of dangerous temperature intervals in products on a phosphate binder.

According to French researchers, $Mg(H_2PO_4)_2 \cdot 2H_2O$ transforms into $Mg(H_2PO_4)_2$ in the range of 90-200°C; at 200–350°C, it transforms into $MgH_2P_2O_7$dihydropyrophosphate; at 400–450°C, it transforms into amorphous polyphosphate $(Mg(PO_3)_2)_n$; at 500–800°C, this compound transforms into $Mg_2P_4O_{12}$tetrametaphosphate [24].

The work of Japanese scientists provides data on possible transformations of phosphates:

$Mg(H_2PO_4)_2 \cdot 2H_2O \rightarrow$ $Mg(H_2PO_4)_2 \rightarrow$ $MgH_2P_2O_7 \rightarrow$ $Mg_2P_4O_{12}$ (at 95, 240 and 435°C, respectively)

$Mg(H_2PO_4)_2 \cdot 2H_2O \rightarrow$ $Mg(H_2PO_4)_2 \rightarrow$ $MgH_2P_2O_7$ + amorphous phase→ $Mg_2P_4O_{12}$ (at 110, 240, and 430–650°C, respectively) [25].

Fractographic studies of the obtained carbon-containing lightweight concretes on a magnesium phosphate binder showed the presence of needle-like aggregates of newberyite, which help to hold the mixture components together, providing strength. Under heat treatment conditions, the following transformations were noted: newberyite at 150°C passed into hydroorthophosphate monohydrate $MgHPO_4 \cdot H_2O$. At 200°C, $MgHPO_4 \cdot H_2O$ was transformed into $MgH_2P_2O_7$dihydropyrophosphate. After 400°C, the lines of $Mg_2P_4O_{12}$tetrametaphosphate are marked on the X-ray diffraction pattern, from 700°C orthophosphate $Mg_3(PO_4)_2$.The compounds obtained in our experiments are somewhat different, probably due to the conditions for obtaining concrete or the characteristics of the component composition.

Features of the interaction of ammonium phosphates affect the structure of the surface of carbon-containing lightweight concretes on a magnesium-ammonium phosphate binder. In addition to newberyite, crystals of struvite and ditmarite are noted.

The works of Quanbing Yang, Xueli Wu, Nan Yang and other researchers emphasize that struvite is a binding phase The presence of ditmarite in the samples may be due to the presence of an insufficient amount of water during hydration or dehydration of the struvite due to heating of the cement by exothermic reaction when salt is introduced [26-29]. Sarkar was proposed another mechanism: an insoluble diffusion-barrier coating is formed around the MgO grains, consisting of polyphosphate units, cross linked by Mg^{2+} ions and coinciding with the onset of setting. Over time, this gel slowly crystallizes into an interconnected struvite microstructure, which greatly contributes to the initiation of cement paste hardening [30].

The effectiveness of the use of briquette from forsterite with magnesium phosphate cement was shown in earlier studies by the authors [2]. Before using the magnesium ammonium phosphate binder in lightweight concrete, experiments were again made with a combination of different charge components. Samples with forsterite briquette and granules showed strength up to 5 MPa, and fell apart with unfired raw materials.

Let us once again emphasize the importance of the component composition of the charge and the type of binder used. It should be noted that the compressive strength of lightweight concretes based on magnesium phosphate cement increases with an increase in the amount of briquette in the charge. The highest strength (3 MPa) was obtained from the mixture (40% granules + 60% briquettes < 0.063 mm).

The introduction of a combined binder using lignosulfonate is associated with a violent reaction between the components of the concrete composition and magnesium phosphate. Lignosulfonate served as a moderator of the interaction rate. Ultimately, the highest strength index (10 MPa) was in the sample from the mixture (40% granules + 60% briquettes <0.063 mm) with a ratio of MPC / LST = 80/20. Note that the compressive strength and density depend not only on the granule/briquette ratio in the batch, but also on the MPC/LST ratio.

For example, the strength index increases with the content of 20-30% of the briquette in the charge and the ratio of MPC / LST = 50:50 or 40-60% of the briquette in the charge and the ratio of MPC / LST = 80:20. In general, for samples with a high content of the briquette, there was a tendency to decrease in the strength index with a decrease in the MPC content in the combined binder. Thus, the proposed joint use of a magnesium phosphate binder with lignosulfonate is an effective tool for improving the characteristics of concrete.

When receiving concrete on ammonium phosphate cements, a dry mixture of charge components and salt is poured with water or a solution of magnesium phosphate. It is noted that not only the type of salt, but also the liquid for obtaining a concrete solution has an impact on the properties. Thus, light concrete with a compressive strength of 3-4 MPa was obtained from a charge (30% granules + 70% briquette <0.063 mm) on $(NH_4)_2HPO_4$ and from a charge (40% granules + 60% briquette <0.063 mm) on $NH_4H_2PO_4$ using water. While wetting with a solution of magnesium phosphate a mixture of charge components (50% granules + 50% briquette <0.063 mm) and $NH_4H_2PO_4$ led to an increase of compressive strength to 7 MPa.

Further study of lightweight concretes should be devoted to the study of their characteristics when heated, paying special attention to the change in the volume of the samples.

4. Conclusions

The technology of lightweight concrete from waste of Kovdor GOK and carbon containing granules with cements of magnesium or ammonium magnesium phosphates has been developed. It is considered economically viable due to the low cost of the raw materials used in comparison with olivine or dunite.

XRD, optical microscopy and SEM studies have identified the formation of new phases in concrete. Concretes with magnesium phosphate binder contain forsterite, periclase, newberyite $MgHPO_4\bullet3H_2O$:

$$MgHPO_4\cdot3H_2O\rightarrow(150°C)\ MgHPO_4\cdot H_2O\rightarrow(200°C)MgH_2P_2O_7\rightarrow(400°C)\ Mg_2P_4O_{12}\rightarrow(700°C)\ Mg_3(PO4)_2.$$

Struvite, dittmarite, bobierrite are formed by use of monoammonium phosphate and struvite, ditmarite, newberyiteare formedin by use of diammonium phosphate with a forsterite briquette in concretes

The experimental dependencies of lightweight carbon-containing concrete are presented:

- compressive strength and density from ratio granules/briquette in the charge (for the magnesium phosphate binder)
- compressive strength and density from ratio granules/briquette in the charge and the ratio MPC/LST (for the combined binder)
- compressive strength from ratio granules / briquette and the type of binder (for the ammonium phosphate binders)

Carbon-containing lightweight concretes based on magnesium or ammonium-magnesium phosphate cements can use in steel industry.

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