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COLLOIDAL STRUCTURES FOR STRENGTHENING MINERAL AND ORGANIC BINDERS ARE THE FUTURE OF AN ENVIRONMENTALLY FRIENDLY AND CLIMATE-RESISTANT TRANSPORT INFRASTRUCTURE

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ABSTRACT

The article presents the outcomes of fundamental laser research, experimental studies, and long-term monitoring of roads constructed using belite cements and asphalt binders. These materials, rich in bicalcium silicate (C2S-belite 50–80%), ensure road concrete durability for up to 50 years without repairs. Laser studies revealed the unique colloidal structures of belitic cement, which include calcium hydrosilicates (CSH), enhancing cement hydration and promoting self-healing (thixotropy) and hardening under load (rheopexy).

Belite cements enable efficient year-round road construction in Kazakhstan's harsh climate, with roads enduring for 35–48 years due to long-term hardening. This approach revives the theory of V. Michaelis, emphasizing the durability of colloidal structures over crystalline alite cements, which degrade after 20–30 years due to incomplete hydration. The novelty of this work is supported by patents, shedding light on the enduring properties of ancient Roman concrete.
Asphalt concrete, typically lasting 10 years, retains its properties for recycling. The 2016 Eurobitumen Congress highlighted fully recycled asphalt layers. In Kazakhstan, researchers developed an innovative asphalt concrete theory, extending service life by preserving the colloidal binder structure and preventing bitumen aging.

This research underlines the advantages of nanotechnology in road construction, confirmed by laboratory tests and monitoring roads in service for over 35 years. For the first time, Kazakhstan demonstrates the environmental and structural limitations of traditional Portland cement and bitumen, advocating for advanced materials to ensure sustainable and durable transport infrastructure.

KEY WORDS:

transport infrastructure, laser research, colloidal structures, nanostructured concretes and asphalt concretes, durability, ecology.

INTRODUCTION

The problem of asphalt concrete quality is being actively addressed both in Kazakhstan and abroad. The main attention is paid to the properties and quality of bitumen as a binder in the composition of asphalt concrete, since. It is believed that the quality of bitumen significantly affects the quality of mixtures and the durability of asphalt-coated concrete, bitumen itself cannot be a binder in asphalt concrete, no matter how high-quality it is, no matter what modifiers and plasticizers are added to it [1]. The main criterion, according to the author, for obtaining a good asphalt coating should be the neutralization of acidic components of bitumen by adding a mineral powder with a high content (at least 95%) of CaCO3 + MgCO3. It is believed that it is necessary to improve the composition of asphalt concrete and the regulatory documents applicable to them, and the adhesion of binders to stone materials is not a prerequisite for achieving good water resistance of asphalt concrete. But despite all the ways and means of improving the quality of asphalt concrete, numerous damages appear on the coatings.

The most difficult conditions for asphalt concrete operation are the autumn-winter-spring periods, characterized by a significant daily amplitude of temperature fluctuations. At negative temperatures, asphalt concrete acquires the properties of a fragile body, and at high positive temperatures - plastic properties.

The most common damages to asphalt concrete road surfaces are cracks, discolorations and plastic deformations (rutting, combing, swellings, etc.) [2].

To prevent cracking, it is necessary to improve the properties of asphalt concrete, as well as to improve the design of the pavement as a whole. In order to eliminate peeling, discoloration and plastic deformations, it is necessary to improve the composition of the asphalt products used. It is possible to prevent the formation of plastic deformations on coatings by using asphalt concrete with increased mechanical properties.

New concepts indicate the need for a radical revision of the road design methodology still in force in Kazakhstan and Russia, taking into account an increase in the durability of roads by 50 years, in order to make them payback. At the same time, it is well known that binders in asphalt concreteis not pure bitumen, but an asphalt binder consisting of bitumen and mineral powder [3]. Fine mineral powder with a specific surface area of up to 3500–4000 cm2/g together with bitumen form a colloidal solution [3], which creates conditions for thixotropic colloidal hardening of asphalt concrete. The strength of purely bitumen bonds is tens of times lower than the bonds formed through joint interaction with mineral powder. Therefore, the development of belite cements, created on the basis of mineral waste, is a promising technology in road construction, which is relevant

METHODS

A small part of the research on improving the physical and mechanical properties of asphalt concrete by using self-cementing materials from industrial waste in their compositions, the strength gain in which occurs over a long time, is given in this work.

The compositions of asphalt concrete mixtures and the results of their testing are given in Tables 1-3.

The data from Tables 1 indicate that the samples are formed from an asphalt concrete mixture using blast furnace slag (fractions of 0-10 mm) as a fine filler, and ground slag as a mineral powder, have increased physical and mechanical properties compared with the indicators as control samples, as well as the requirements of GOST. Thus, the data of the compressive strength at a temperature of +20 0C (R20) and +50 0C (R50) exceed on average 2.5 times, and the tensile strength at +75 0C (R75) exceeds the values of the control samples by 3.9 times. It should also be noted that the strength limits at 50 0C (R50) and at 75 0C (R75) of asphalt concrete using blast furnace slag are almost the same, whereas the same indicators of control samples at (R75) are 40% lower than at 50 0C (R50). Apparently, the increased (2.5 times) indicators of mechanical properties, especially at 50 0C (R50) and at 750C (R75,) indicate an increase in the durability of asphalt concrete with the addition of blast furnaces, and increased tensile strength during bending (over 2 times) indicates increased shear stability, as it distributes wheel loads well over a large area of the pavement base, preventing the formation of a rut.

The data in Table 4 show that the main strength gain occurs within 7 to 28 days, and in the future the strength increases very slowly.

Table 1 – Test results of hot fine-grained asphalt concrete mix type B (7 days after molding)

Composition of the mixture	Average density, g/cm3	Water supply, %	Swelling, %	The porosity of the miner. parts, %	Remaining porosity, %	Compressive strength, MPa					R stretching t=75	Long-lasting water resistance
						R_{20}	R_{20}^{water}	R_{50}	R_{75}	R_0 / R_0^p		
Composition 1 (control) Crushed stone.fr 5-20мм-45% sand and gravel mixture fr. 0-5мм - 49% Min. Powder -6% Bitumen 60/90 - 6,0%	2,38	2,61	0,33	15,6	3,6	4,9	3,82	1,3	0,8	12,7 / 3,5	0,6	0,76
Composition 2 Crushed stone.fr.5-20мм-42% Blast furnace slag seeding fr. 0-10мм - 50% Ground slag 8% Bitumen 60/90 - 5,5%	2,36	3,0	0,1	15,8	4,0	5,8	5,5	3,3	3,1	9,3 / 5,5	1,6	1,2
Composition 3 Crushed stone.fr .10-20мм-45% Blast furnace slag seeding fr. 0-10мм - 47% Ground slag -8% Bitumen 130/200 - 5,5%	2,36	3,2	0,09	15,2	3,8	5,1	5,2	3,8	3,3	9,4 / 5,5	1,55	1,2
Requirements of GOST 9128		2,5-6,0	No more 0,5	15-19	3,0-7,0	No more 2,5		No more 1,3		No more 13 / 3-7,5		No more 0,75

The high deformative properties of slowly hardening concrete indicate the high dispersion and tensile strength (cohesive bond) of the new formations of cement stone of belite cements (figure 1).

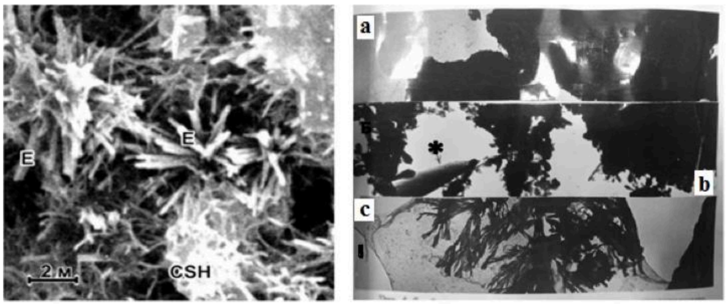

Figure 1 – Microstructure of cement stone: on the left – alite cement stone, after 28 days, E – ettringite crystals, CSH – C-S-H fibers [6]; on the right – belite cement stone [7]: a – after 28 days; b – after 90 days, tube (*) CSH; c – after 180 days, C-S-H fibers. Electron microscope photo – magnification 25000

X-ray phase, thermographic (not shown) and electron microscopic studies shown in the photo (figure 1) confirm that in such concretes, the above technological and operational advantages are provided mainly by the gel-like hardening structure of belite cements.In the structure of traditional alite Portland cement stone, on the contrary, the insignificant content of gel-like two calcium hydrosilicates fills only the free space inside the main frame formed by the fusion of large crystalline hydrates.

Table 2 – Results of selection of compositions of asphalt-mineral mixtures for monolithic road base

№. Mixture composition	Materials used in the mixture, %						
	Asphalt concrete granulate	Crushed stone from blast furnace slag fr. 5-20	Crushed stone from blast furnace slag fr. 20-40	Belite binder without grinding	Activator cement M-400	Water	Bitumen
1	40.0	10.0	30.0	20.0	2.0	3.0	2
2	40.0	10.0	30.0	20.0	2.0	3.0	0
3	30.0	20.0	30.0	20.0	2.0	3.0	2.0
4	50.0	10.0	25.0	15.0	2.0	3.0	2.0
5	50.0	10.0	25.0	15.0	2.0	3.0	0
6	60.0	10.0	20.0	10.0	2.0	3.0	2.0
7	70.0	10.0	15.0	5.0	2.0	3.0	2.0
8	70.0	10.0	15.0	5.0	2.0	3.0	0

Table 3 - Test results for samples made of asphalt-mineral concrete after steaming

№. Mixture composition	Density, g/cm^3	Strength of steamed samples, Rcom, MPa at temperatures		
		0°C	**20°C**	**50°C**
1	2.22	3.56	2.15	0.78
2	2.27	3.52	3.25	1.47
3	2.31	3.48	2.27	0.79
4	2.25	3.62	2.27	0.82
5	2.24	3.51	3.35	1.51
6	2.20	3.62	3.20	1.44
7	2.21	3.68	2.18	0.72
8	2.31	3.58	3.39	1.41

Table 4 – Strength of samples of asphalt-mineral concrete cores cut from the base (of different ages)

Sample age	Compressive strength R, MPa at t°C			
	20 °C	**50 °C**	**0 °C**	**-10 °C**
1 day	4.81	2.29	7.4	7.9
2 years	9.44	3.32	12.5	18.6
3 years	13.15	4.22	13.8	22.5

RESULTS AND DISCUSSION

The test results given in tables 2, 3, 4 showed that the introduction of additional bitumen in an amount of 2% is unnecessary; Strength decreases and bitumen deposits appear on the road. Therefore, the road was built using composition №8, with a maximum amount of asphalt granulate containing 70%. The strength of asphalt-mineral concrete, as well as traditional asphalt concrete, depends on the core testing temperature (table 4). This indicates that in asphalt-mineral concrete, at the microstructure level, the mineral belite binder as a mineral powder and the bitumen contained in the asphalt granulate interact together. This is in good agreement with the conclusions made on organo-slag-alkali mixtures previously by Professor N.V. Gorelyshev [3].

Nanostructured asphalt-mineral concretes and road concretes based on nanostructuring cements meet the requirements of modern concepts of “eternal roads” and “roads with long life” in the USA and EU countries, which allow the construction of road structures with a service life of at least 50 years [2.5, 16-19].

The innovative concept for the construction of highways (road structures) provides for complete resource conservation at all stages of the “life activity” of the highway: during construction, repair and reconstruction, with complete recycling of all materials and their reuse.

In the table 1 shows a comparison of the chemical and mineralogical compositions of traditional Portland cements (here in after referred to as alite cements) and slow-hardening high-tech cements (hereinafter referred to as belite cements).

Table 5 - Chemical and mineralogical compositions of alite cements and slow-hardening belite cement mixtures

Kinds cements	Chemical composition, mass. %			
	CaO	SiO_2	Al_2O_3	Fe_2O_3
Alite	60-67	17-25	3-8	0.2-6
Belite	33-46	39-61	3-10	3-5
	Mineralogical composition, mass. %			
	C_3S(Alite)	C_2S(Belit)	C_3A	C_4AF
Alite	40-75	5-25	2-15	5-20
Belite	10-35	60-85	3-5	2-7
Note - conventional names of cements are given based on the predominant content of minerals: C_3S - alit, C_2S - belite.				

Physico-chemical fundamental studies have confirmed [4,5,7] that the mineralogical composition of belitic slag cement stone mainly consists of slow-hardening two calcium hydrosilicates C2S-belite from 50% to 85%. Traditional Portland cements mainly consist of fast-hardening hydrosilicates C3S-alite up to 65% and up to 20% C2S-belite.

The formation of the structure of a slow-hardening slag cement stone, during its hardening for 8 years, is shown for clarity in photographs of fractures of cement beams tested for tensile bending, shown in Figure 2.

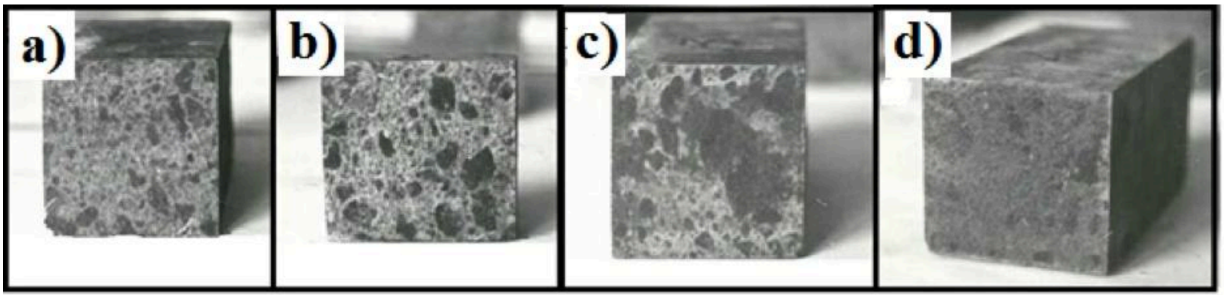

Figure 2 – Photographs of fractures of samples hardened under normal conditions and tested after:
a – 1 year; b – 3 years; c – 6 years; d – 8 years

The nature of the slow decomposition of cement grains and the appearance of neoplasms can be clearly seen in the photographs (Figure 2). The number of gel-like neoplasms in the samples increases with increasing age of the samples. But even after 8 years of hardening under normal conditions, non-hydrated grains are observed in cement samples, which indicates the potential of cement for further hardening. In immersion, the gel is a colorless isotropic mass with a refractive index of 1.330 – 1.567. The number of gel-like neoplasms in samples increases with increasing age of the samples. But even after 8 years of hardening under normal conditions, unhydrated grains are observed in cement samples, which indicates the potential of cement for further hardening. X-ray patterns of belite cement stone shown in figure 3 confirm the data obtained.

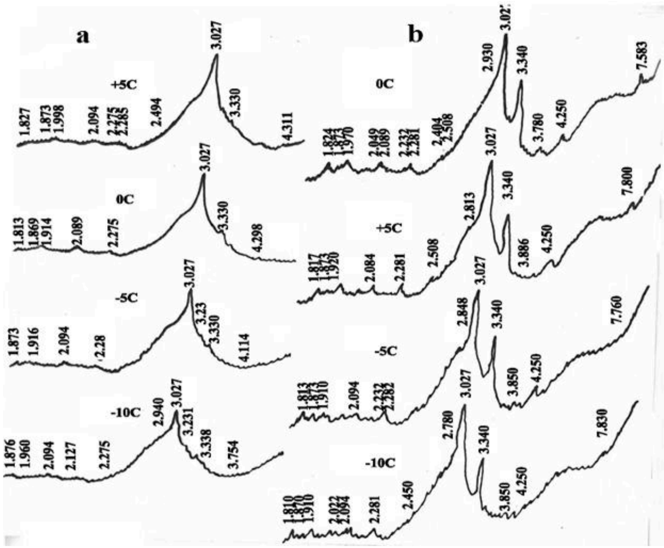

Figure 3 – X-ray patterns of belite cement stone samples, hardened for 3 months at temperatures +5; 0; -5; -10 oC: a) – after 1 month of aging under normal conditions; b) – without aging under normal conditions

Thus, regardless of the temperature regimes of hardening of belite cement stone (within the limits of the experiment) and the holding time, the phase composition of the new formations does not undergo any significant changes. The slowing down of cement hydration processes with decreasing hardening temperature is evidenced by a decrease in the diffraction line corresponding to the interplanar distance of 3.027 Å, compared to 3.039 Å, during hardening at positive temperatures, described in detail by Kh.F. Taylor [6].

Figure 4 shows the results of testing a number of samples 5, 6, 7, 8 in comparison with samples that were constantly hardened under normal conditions.

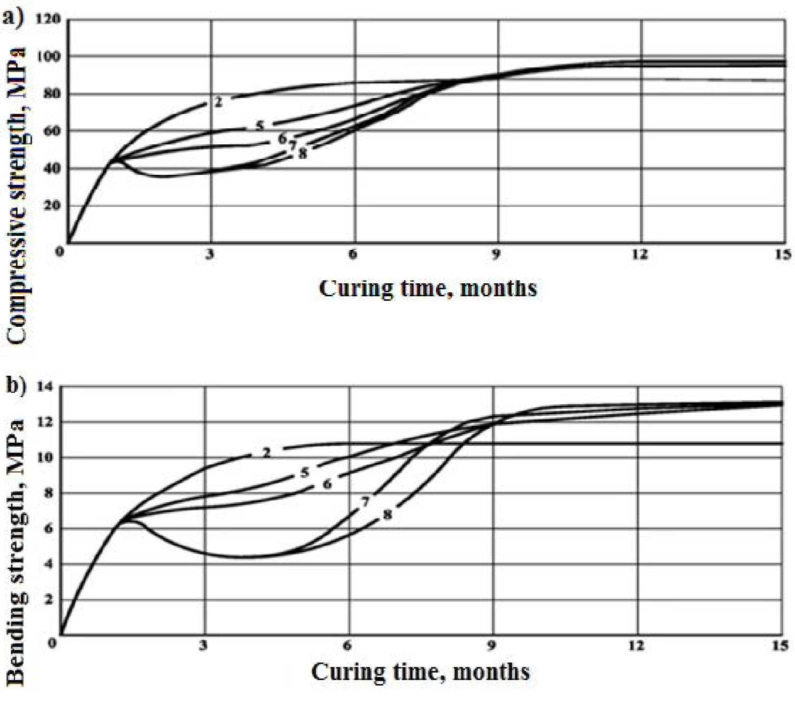

Figure 4 – Kinetics of changes in the strength of belite cement stone samples over time: 2 – constantly under normal conditions; 5,6,7,8 – pre-conditioned for 1 month under normal conditions, then respectively at +5°C; 0°C; -5°C, -10°C, then again under normal conditions: a - compressive strength; b – tensile strength in bending

Data indicate that low positive and negative temperatures slow down the hardening process of cement previously kept under normal conditions. Moreover, the lower the hardening temperature, the slower the strength gain occurs.

The greatest destruction in road concrete occurs during alternating freezing and thawing, with the temperature passing through 0 °C. Therefore, the main requirements for road concrete are their frost resistance during long-term operation of highways.

Considering that temperature transitions through 0°C within one year, only in Southern Kazakhstan reach up to 80-90 cycles, experimental construction of a number of roads using slag concrete foundations was carried out in winter.

Table 6 – Results of testing samples of slag concrete from mixtures selected during the construction of pilot production sections of highways (1. Method of mixing on the road, 2. Mixing in the installation)

Sample molding date, year	Sample storage conditions	Compressive strength, kgf/cm², age, days				Composition of gravel-sand mixture
		30	90	360	540	
1	2	3	4	5	6	7
1.	Highway "Alexandrovka-Nesterovka" (15% slag binder)					
25/11/76y.	in the laboratory on air	42 20	162 110	116 198	168 252	particles larger than 5 mm from 40% to 50%
25/11/76y.	in the laboratory on air	35 25	170 100	176 210	179 245	– // –
26/11/76y.	in the laboratory on air	40 18	175 118	183 209	190 260	– //–
29/11/76y.	in the laboratory on air	30 21	184 110	185 207	184 247	–// –
2/12/76y.	in the laboratory on air	37 22	181 105	180 200	180 235	–// –
3/12/76y.	in the laboratory on air	35 27	186 116	191 213	192 250	particles larger than 5mm from 50 to 60% (local)
6/12/76y.	in the laboratory on air	48 20	187 109	195 204	197 243	–// –
10/12/76y.	in the laboratory on air	39 15	180 115	187 210	190 254	– //–
16/12/76y.	in the laboratory on air	44 16	185 120	190 201	191 230	–// –
2.	Fogelevka-Zhdanovo highway (10% slag binder)					
5/12/77y.	in the laboratory on air	20 15	125 87	130 146	131 157	particles larger than 5mm from 40 to 50%
7/12/77y.	in the laboratory on air	22 14	115 89	136 151	134 163	–// –
9/12/77y.	in the laboratory on air	19 12	100 78	128 141	130 168	–// –
14/12/77y.	in the laboratory on air	17 13	172 86	135 148	134 159	–// –
19/12/77y.	in the laboratory on air	21 15	124 97	137 152	140 167	–// –
22/12/77y.	in the laboratory on air	18 14	106 79	132 146	130 170	– //–
23/12/77y.	in the laboratory on air	16 10	118 80	139 156	143 184	–// –

From the test results of samples from slag concrete mixtures selected during the construction of sections on the roads "Alexandrova - Nesterova" and "Fogelevo - Zhdanovo" under conditions of low positive and negative temperatures, it follows that the final strength indicators of slag concrete maintained in natural temperature conditions for 1.5 years, including in winter conditions, exceed the strength of hardening samples in the laboratory by an average of 10-15%.

In July 2016, an examination of experimental sections of roads built using cinder concrete pavements with a wear layer of cold asphalt concrete was carried out. It has been established that the roads are in good technical and operational condition, there are no potholes or subsidence, and there are temperature transverse cracks at a distance of 12-15 running meters. In some places the edge of the asphalt concrete pavement was destroyed. Slag concrete foundations, which have been in operation for 39-40 years, do not have any deformations, except for temperature cracks.

A visual inspection and testing of cores from the experimental site on the Fogolevo – Zhdanovo highway was carried out in the spring of 1989, i.e. 33 years after construction and a survey carried out in July 2016, i.e. after 27 years, it showed that the experimental site is in good operating condition. There are longitudinal and transverse cracks. The distance between transverse cracks, compared to 1989, was reduced to 12-15 m, with an opening width of 2-3 mm. In some places the coating is a layer of asphalt concrete, there are potholes, but the cinder concrete is in good condition and there are no defects. For 33 years of operation, no repair work has been carried out on this road.

Figure 5 – Photo - 2005. Testing of samples of beams made from cutting out the lower layer of cinder concrete coating for bending strength (the structure of the beam is heterogeneous - the filler is a local gravel-sand mixture)

In the table 7 presents the results of testing cores drilled in 1989 y. from the bottom layer of concrete pavement and beams made from concrete cut in 2005 from the Fogolevka - Zhdanovo highway, built in December 1977.

Table 7 – Results of core testing in 1989 and beams 2005 from the lower layer of concrete pavement of the Fogoleva - Zhdanovo highway

Name of the measured indicator	Core testing 1989, MPa, (concrete age 12 years)	Testing of core beams 2005, MPa, (concrete age 28 years)
Compressive strength	36.4; 36.7; 36.5 Average 36.5 (M 350)	48.6; 49.0; 48.8 Average 48.8 (M 450)
Bending strength	-	8.6; 8.3

The results of a study of the technology for constructing slag concrete pavements with a wear layer of asphalt concrete in winter and monitoring of experimental sections of roads built in summer and winter are confirmed. This indicates that road slag concrete has the property of self-healing and long-term hardening, under the influence of constant dynamic vibration transport and climatic loads, during long-term operation of roads. Figure 5 interprets the results of testing cinder concrete foundations for a number of road sections built in 1976-1984. Strengthening of slag concrete has been taking place for 30-40 years during road operation.

The results of petrographic, X-ray diffraction (figure 3), differential thermal analyzes and observations using a scanning electron microscope that we obtained showed that during the hardening of belite cements, the main structure-forming new formations in concrete are gel-like low basic calcium hydrosilicates of type C–S–H [7].

The experimental results obtained suggest that of all the theories of hardening of mineral binders, the colloid-chemical theory of V. Michaelis [6] can be distinguished, which, obviously, will be more justified for explaining the hardening processes of belite cements.

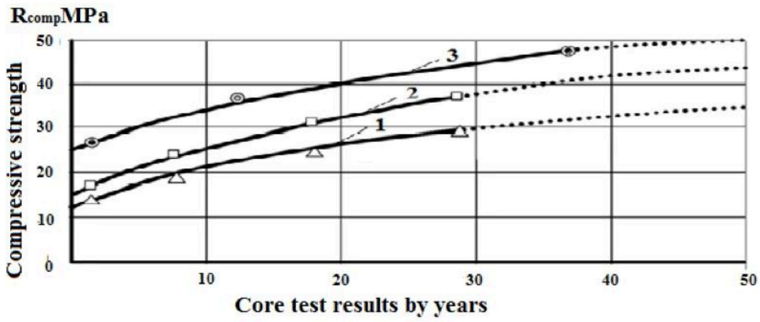

Figure 6 – Kinetics of strength gain of self-healing concrete road foundations experimental sections of roads built in 1976-1984. 1, 2, 3 – spossession of belit (C2S) in cements – 60; 70 and 80% respectively

At normal temperatures, C–S–H hydrosilicates are formed in the form of plate-like submicrocrystals, the average length of which is close to 10,000 Å (1 μ), and the width and thickness are, respectively, 360 – 560 Å and 20 – 30 Å. Due to the very small size of hydrosilicates, as well as their ability to adsorb water on their surface, hydrosilicates have the properties of colloids. Loss or saturation of water is accompanied by a change in the distance between the layers of the crystal lattice of C–S–H hydrosilicate, which leads to changes in the strength of the material. Further keeping the material in humid conditions ensures the adsorption of moisture by the gel, replenishment of the binding water films between the layers of the hydrosilicate lattice and restoration of the strength of the material.

The main structure-forming component in belite cement stone is low-basic calcium hydrosilicates C–S–H, which are amorphous glue, nanosized [7-9], which have the property of long-term thixotropy. Concrete is the most common building material, being a nanostructured multiphase composite material that matures over time. It consists of an amorphous phase, nano- to micrometer-sized crystals, and bound water. The properties of concrete, like the destructive characteristics, exist in a multi-scale range (from nano- to micro- and macro-levels), when the properties of the material at each level are formed on the basis of the properties of the previous cell of a smaller size [9-10]. The amorphous phase of calcium hydrosilicate (C–S–H) is the "glue" that holds the components of concrete together [11,12] and is it self a nanomaterial. Recently, due to interest in the formation of stable structures of concrete [9, 13, 14], much attention has been paid to nanoscale modification of the C–S–H structure to create hybrid, organic, cementitious nanocomposites. The layered structure and the tendency of silicon chains (except tetrahedral) to structural defects in C–S–H [9, 11] open up the possibility of introducing a variety of organic molecules into the basic structure of C–S–H. Three schemes have been proposed for hybridization or introduction of "guest molecules" into C–S–H. The first scheme interpolates organic molecules into the C–S–H layer [15].

We have studied the properties of belite nanocements, such as self-healing, in order to develop technology for road construction work at different temperatures for year-round construction and operation of highways.

This is also confirmed by the change in the amount of strongly bound water in the cement stone of samples maintained at different temperature conditions (figure 7).

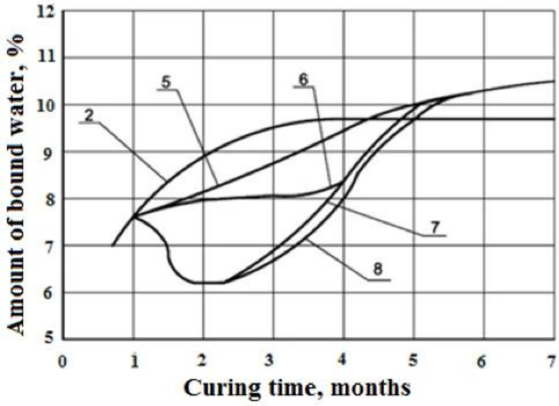

Figure 7 - Kinetics of changes in the amount of strongly bound water in belite cement stone during hardening at different temperatures: where 2 - constantly under normal conditions, 5, 6, 7 and 8 - at the beginning one month under normal conditions, then three months at temperatures: + 5oC, 0oC, -5oC and -10oC and again for three months under normal conditions.

The results of changes in the amount of strongly bound water in cement stone (figure 6), established by measuring the mass loss of samples after calcination at 1000 °C, previously held at 105 °C, confirm the following. The kinetics of changes in the strength (figure 3) and the amount of strongly bound water (figure 11) of cement stone, depending on the sample holding temperature, are similar, which confirms the reliability of the theoretical premises about the self-healing properties of belite cement. When the cement stone is kept at low temperatures (samples 5–8), the decrease in strength (figure 3) is accompanied by the displacement of strongly bound water (figure 6) from fibrous formations in the amount of 10–30% of the mass of the available moisture in their capillaries, and with further aging under normal conditions, their quantity and the strength of the cement stone are restored within one month. Further aging under normal conditions for three months, the strength and amount of strongly bound water exceeds normal hardening samples. This indicates an intensification of the processes of hydration of cement grains and an increase in the dispersion of new formations at low temperatures, which also increases the strength of cement stone and concrete (figure 3).

In the figure 8 shows the results of tests of the strength of various compositions of road concrete depending on the amount of belite cement, which confirm the conclusion about a long-term increase in the strength of concrete over 2 years.

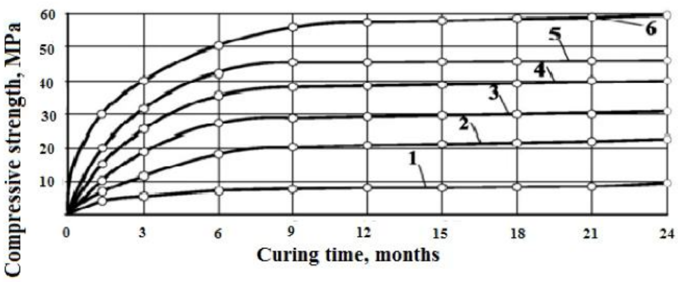

Figure 8 – Kinetics of strength gain of road concrete over time depending on the amount of belite cement: 1, 2, 3, 4, 5, – 10, 15, 20, 25 and 30 wt.% cement respectively

When testing concrete samples aged 90 days for frost resistance, up to 200 freezing and thawing cycles were carried out. As can be seen from figure 13, there is a slight decrease in strength due to the squeezing of moisture from the capillaries and a decrease in its quantity. With further conditioning of the samples under normal conditions, the strength of the concrete is completely restored and even exceeds the strength of the concrete of the 90-day samples (figure 9).

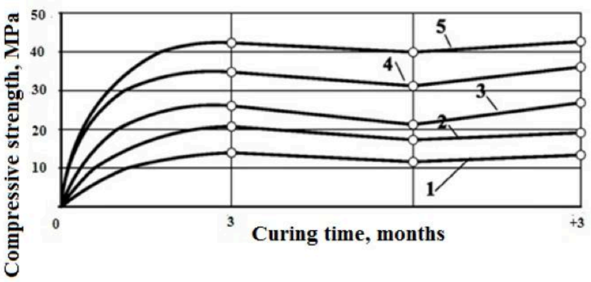

Figure 9 – Self-healing strength of road concrete tested for frost resistance (MRZ-200), depending on the quantity belite cement: 1, 2, 3, 4, 5 – 10, 15, 20, 25 and 30 wt.% cement containing C2S –75–80%

Table 8 - Comparison of indicators: road cement concrete and slow-hardening road concrete using belite cement

Composition of road concrete, wt. %				Strength limits at the age of 180 days, MPa (average of 3)			Modulus of lasticity Ey, MPa
Crushed stone fractions, mm:		Sand M_{pr}=2.5	Cement,%	Rcomp	R_{bend}	R_{bend}/R_{comp}	
5-10	10-20						
15	34	29	Belite cement, 15%	30.9	5.9	0.19	30000
15	34	29	Alite cement, M400.15%	30.0	4.5	0.15	35000

RESULTS AND DISCUSSION

1. Self-healing road nanostructured asphalt-mineral concretes and road concretes have the properties of long-term strengthening of colloidal structures: thixotropy - self-healing from destruction and rheopexy - strengthening from transport and temperature loads.
2. The predominant content of nano-sized hydrosilicates C–S–H in belite asphalt-mineral binder and cement stone gives road concrete the property of self-healing strength from climatic and traffic loads during the operation of highways for more than 40 years.
3. Innovative nanostructured asphalt-mineral concretes and road mineral concretes obtained on the basis of belite nanostructuring mineral powders and cements are high-tech building materials, the novelty of which is confirmed by a number of patents for inventions.

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