Chapter 5

The Enhancement of Asphalt Concrete Surface Rigidity Based on Application of Shungite-Bitumen Binder

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Additional information is available at the end of the chapter

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Abstract

Physical interaction of organic binder depends on bituminous film ability to absorb the mineral particles on the surface. The thick film formation begins with the bitumen amalgamation with mineral powder grains and finishes during the processes of application, seal arrangement and cooling down of asphalt concrete. Active surface centers are on every mineral material and they supply their reactive ability and interaction with bitumen. For proving experimentally and to study the physical and mechanical properties in real operation conditions that were arranged, the blanket was arranged from stone-mastic asphalt with shungite bituminous binder of 500 m long. The monitoring conducted during 3 years indicates that asphalt concrete with shungite binder is subjected to calibration to a lesser degree in comparison with asphalt concrete based on standard powder. For operation reliability of nonrigid road base, it is necessary to estimate and prognosticate asphalt concrete fatigue properties in a blanket. The characterized property appears in such a way that the effect of loads which is significantly smaller than the destructive ones leads to the gradual degradation of fatigue and destruction of the blanket. The results proved that asphalt concrete with shungite bituminous binders has higher operation characteristics.

Keywords: shungite, fullerenes, mineral powder, scan probe microscope, fatigue destruction

1. Introduction

The increase of interrepair period of life duration of road blanket from asphalt concrete is one of the important problems in the road industry. In the conditions of existing trend for the growth of intensity and traffic volume, it is necessary to find new materials and technologies to provide road integrity for the whole period of life cycle. The existing shortage stimulates the finding of the new materials and rock for dolomite and dolomitized limestone replacement during the process of asphalt concrete mixes replacement without their poorer operation quality. One of these rocks is shungite as a unique carbonaceous composite. That is why the research of fine dispersed powder, the substantiation of its application while fabricating asphalt concrete mixes, innovation technologies development of construction of blankets with better operation characteristics is an actual problem.

The high-cost of dolomite mineral powder and stable tendency to its rise stimulate the finding of new materials and technologies which can be used without asphalt concrete operation abilities deterioration.

Shungite is a black rock (flaky stone) from the field near Shunga. Strong strata of this mineral go out onto the shores of the lake Onega near the Tolvuya settlement. There are known five fields: Nizkoozyornoe, Shungskoe, Vikshozerskoe, Myagkozernoe and Krasnaya Selga, the raw materials of which were used for shungite production as a light filler for bitumen.

Shungite is a unique rock consisting of amorphous carbon. It is very active in redox reactions, silicon dioxide, ferric oxide, cobalt, vanadium, titanium and other elements.

Antimicrobial properties of shungite were known even in the seventeenth–eighteenth century that is why Russian tsar Peter I ordered the soldiers to drink water from the vessels with the piece of flaky stone in them.

American professor Semyon Tzipursky from Arizona University determined the uniqueness of carbon in Karelian shungite where it is evenly distributed as conglomerations of 200–300 angstrom. Therefore, they are able to migrate into water in appreciable volumes especially from powder shungite. According to the radiocarbon analysis, shungite age is about 2 billion years.

Carbon (C) from the fourth group of the periodic table is the only element for which valency and coordination number coincide. Thanks to this peculiarity, carbon is able to form the compounds practically with any atoms number in the chain in which there can be any numbers of multiple bonds at any combinations.

The work by Robert F. Curl and Richard Errett Smalley is of great importance. There, a hollow carbon molecule is described as cluster with 60 atoms in it [1]. Theoretically, the structure of 60 atoms (C_{60},) is calculated. The most stable structure of spherical shell is the combination of pentagons and hexagons. Under thermal graphite decomposition, there was synthesized a new substance, the molecules of which have spherical form. So there appeared fullerenes. Different compounds of fullerene molecules with hydroxyl groups were synthesized. Diagram of fullerene molecules is given in **Figure 1**. Fullerene is named by Buckminster Fuller who

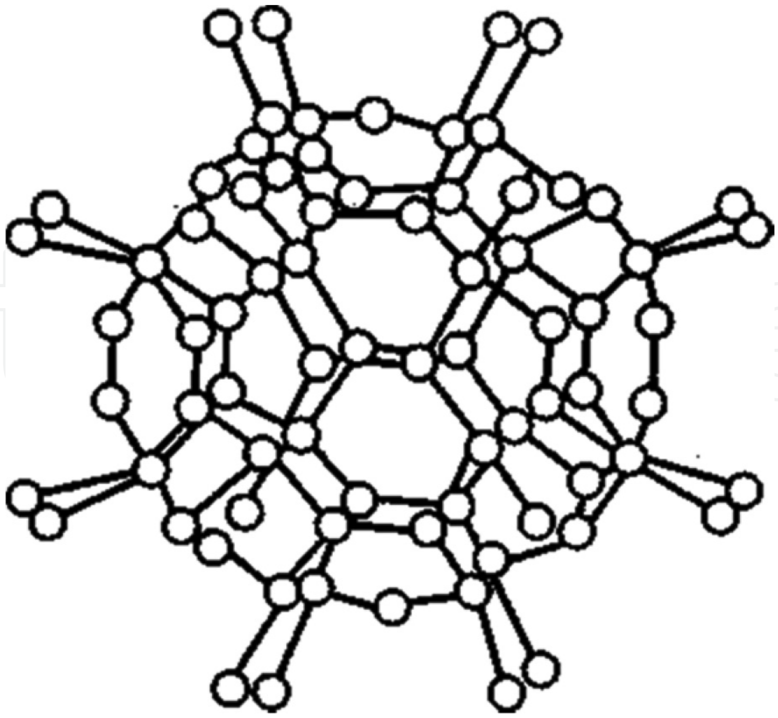

Figure 1. Schematic structure of fullerene is molecule C_{60} with affixed to it radicals (OH).

applied such forms while constructing dome-shaped structures [19]. Schematic structure of fullerene is molecule C_{60} with affixed to it radicals (OH). It is demonstrated in **Figure 1**.

There is a real possibility to obtain different organic compounds based on fullerenes in different spheres of man activity. Particularly, the researches of shungite affecting asphalt concrete surface operating performances are conducted in Voronezh State Technical University (Russia) [2–8].

The attention of the scientists from different countries to the new road construction materials can lead to the appearance of new carbon containing technologies based on fullerenes and graffenes and spreading our conceptions which will influence the civilization development.

2. Researches of materials surface on scanning tester microscope

The effect of shungite mineral powder particles surface nature on asphalt concrete binding agent performances is done by scanning tester microscope NanoEducator. It is for visualization, diagnosis and modification of substance with micro- and nanodimensional level of spatial resolution.

The complex of scanning tester microscope NanoEducator consists of measuring head of scanning tester microscope, electronic block, video camera, connecting cables, computer, eatching probes and also a set of test samples, expendable materials and toolwares. Software Mac OS X is used.

Main characteristics of C3M NanoEducator are presented in **Table 1**.

Characteristics	Quantitative characteristics
Scanning mode	ACM, CTM, lithography
Scanning area	70 × 70 × 10 mkm
Spatial resolution X-Y Z	~ 50 nm ~ 2 nm (depends on radius of probe curvature)
Minimal scanner step	10 nm
Scanning carrent	100–200 nm
Radius of probe curvature	10–100 nm
Time of scanning	30–40 min (depends on scanning area)
Time of set-up	Not more than 10 min
Tested sample size	12 × 12 mm
Sample height	Not more than 5 mm
Environment temperature температура	25 ± 5°C
relative humidity	Not more than 60%
Atmospheric pressure	760 ± 30 mm. of mercury column.
Electric network voltage	220 B
Frequency	50 Hz
	grounding

Table 1. Main characteristics of CZM (C3M) NanoEducator.

Fine powder from limestone, shungite and bitumen binding up to 70 μm was analyzed on the first stage [8].

Samples for scanning were prepared in the following way:

- dispersed powder-like material spreading on an adhesive tape. Before testing there were applied test metering lattices of the height from 21 to 500 nm ((± 1.2–2.5 nm) and the period of 3.0 ± 0.01 μm.

Then, the sample is fixed to the magnetic padding and placed on the magnetic table in the measuring head. After that, the area is chosen for investigation and the surface is scanned.

The state of mineral particles surface plays a great role as the chips, defects and microcracks promote the stronger internal frictions and consequently the better interaction of organic binding and mineral powder.

Mineral powder plays a role of asphalt concrete structure forming component which provides the transmission of voluminous bitumen into film state. Together with bitumen it forms asphalt concrete binding agent substance.

As a result of the analysis, it was determined that limestone powder (**Figure 2**) is characterized with compound surface relief by alternation of peaks and depressions with heights difference from −371 to +429 nm on the scanning area of 8.5 × 8.5 μm. Some evident peaks (light areas)

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and depression zones (dark areas) are observed on the surface under research. The surface unevenness is 0.43 μm. Fractal dimensionality of surface D is 1.73. The structure of shungite surface (**Figure 2** – limestone powder in 3D picture) has less compound relief on the area of 0.46 micromicrone and height difference from −342 to +457 nanomicrone. Shungite surface in 3D is shown in **Figure 3**.

Such structural nature indicates the more dense powder nature and its high value of specific surface and particles aggregation.

The structure of shungite surface has less compound relief on the area of 0.46 micromicrone and height difference from −342 to +457 nanomicrone. Surface fractal dimensionality D = 1.43.

Such nature of the structure indicated that the powder has more dense structure, its specific surface and particles aggregation is high.Bitumen has rather even uniform surface without any defects in structure (**Figure 4**). The scan sample size is 9.5 × 9.5μm, heights difference is from −821 to 820 nm. Fractal dimensionality of surface is D = 1.97. Bitumen surface in 3D is demonstrated in **Figure 4**.

Composite systems are studied on the second stage. The results of scanning show the interaction of shungite and organic binding agent (**Figure 5**). The results of the research by Chernousov D.I. testify the fact, that shungite with its high adsorptive activity relative to organic binding agent promotes its structurization. Bitumen particles penetrate into shungite porous space and fill it.

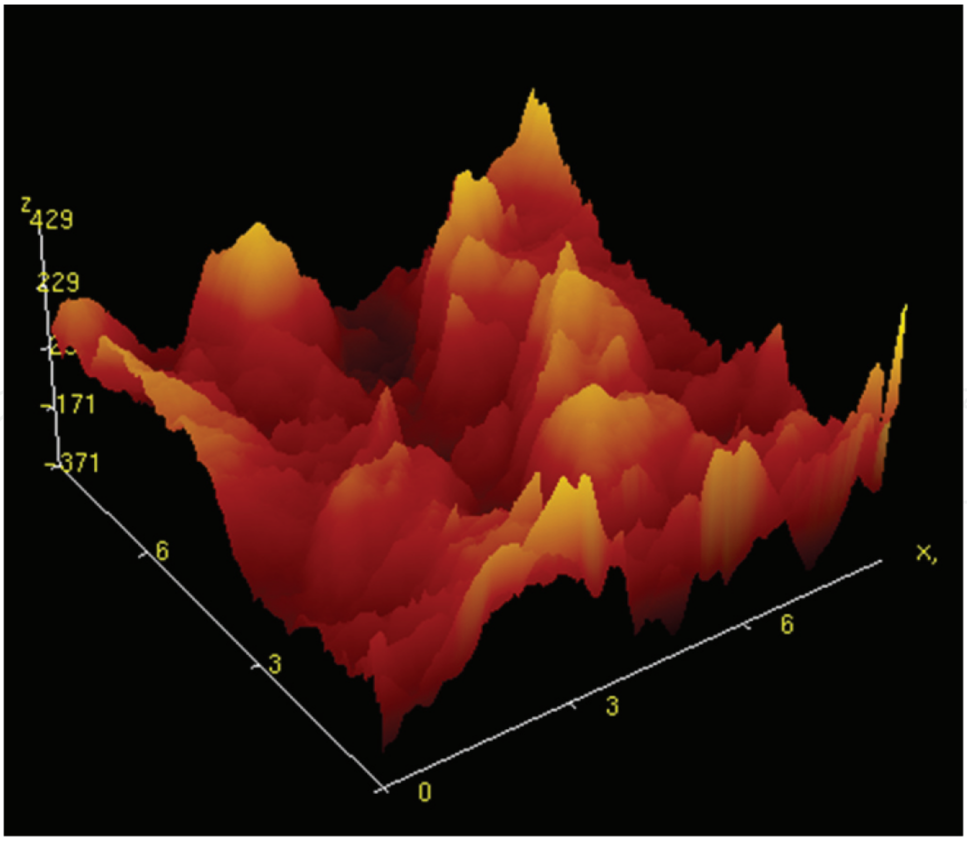

Figure 2. 3D picture of limestone powder. Surface fractal dimensionality D = 1.43.

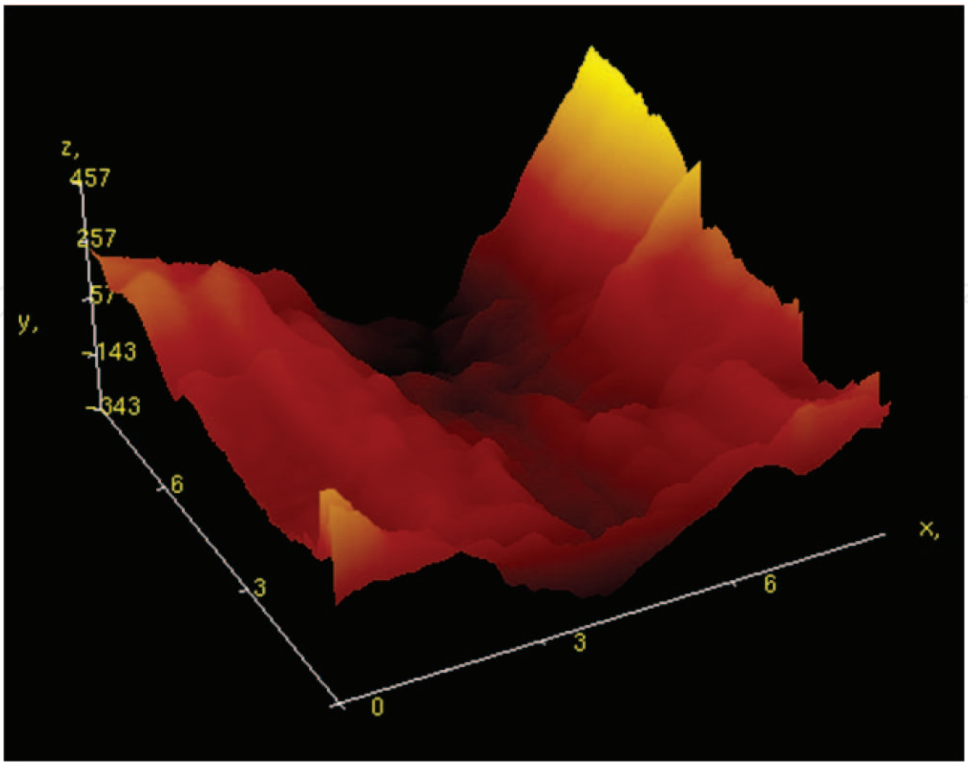

Figure 3. 3D picture of shungit surface.

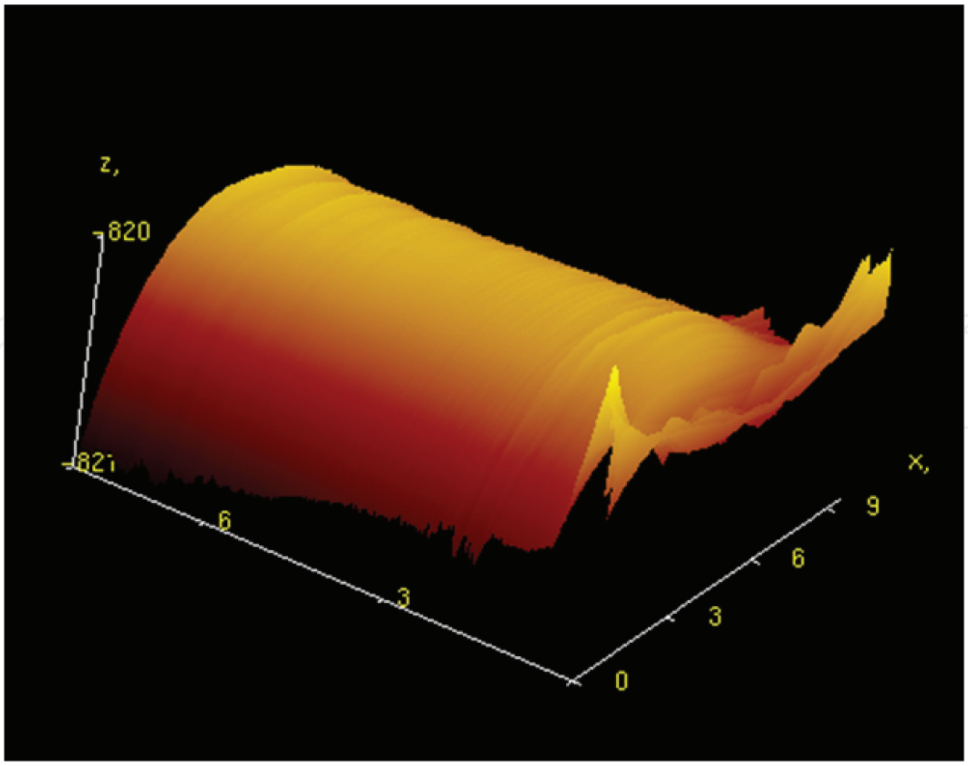

Figure 4. 3D picture of bitumen surface.

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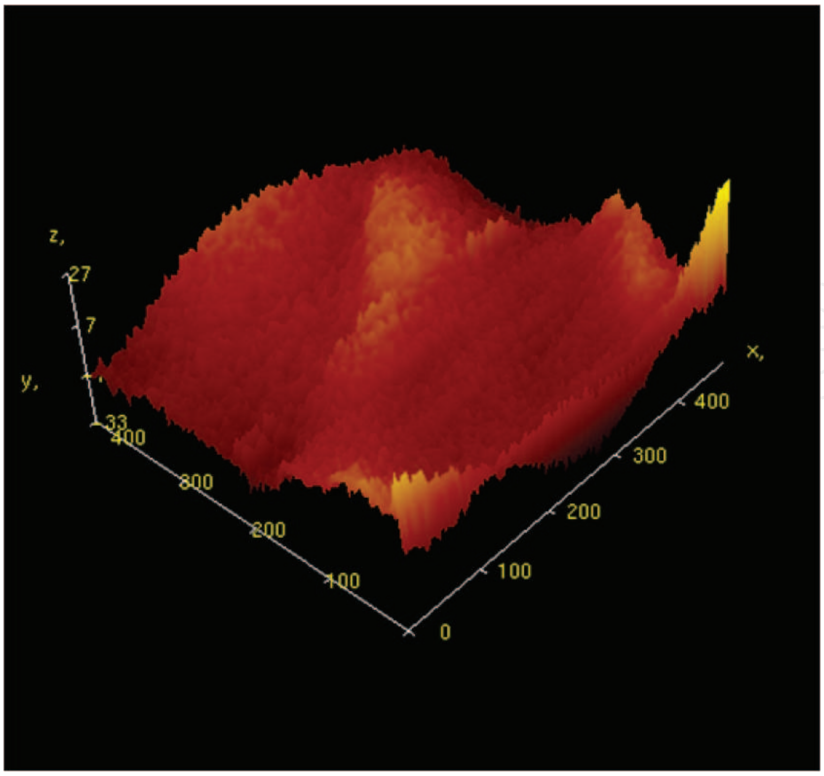

Figure 5. 3D picture of the composite "bitumen-shungite surface".

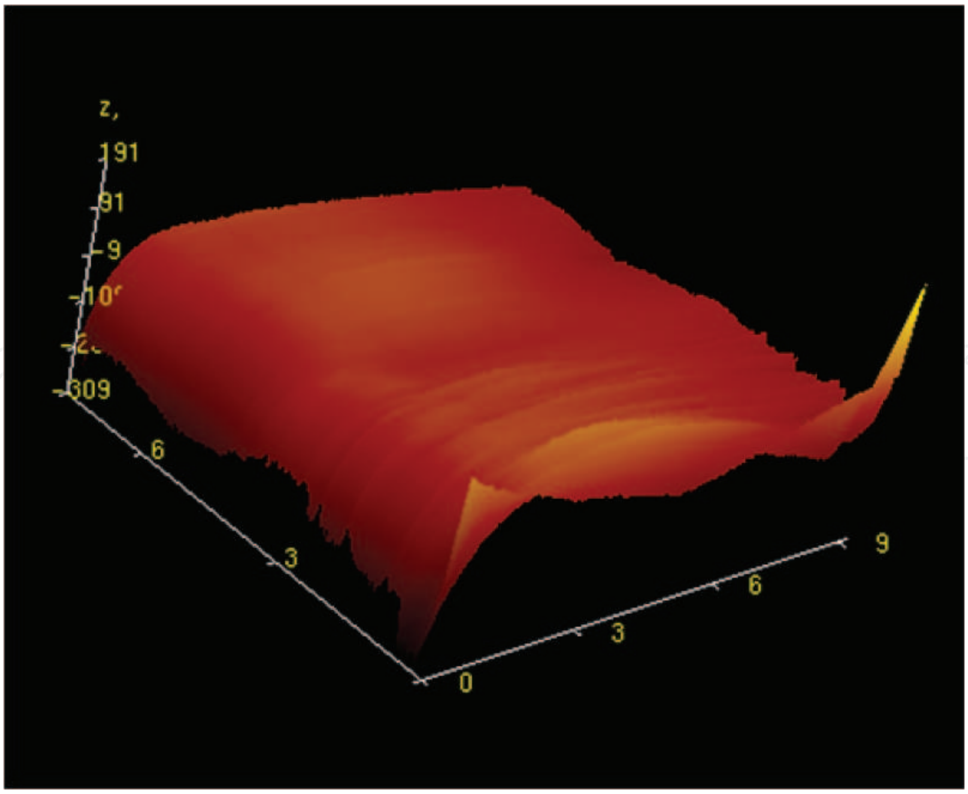

Figure 6. 3D picture of the composite "bitumen-lime stone" surface.

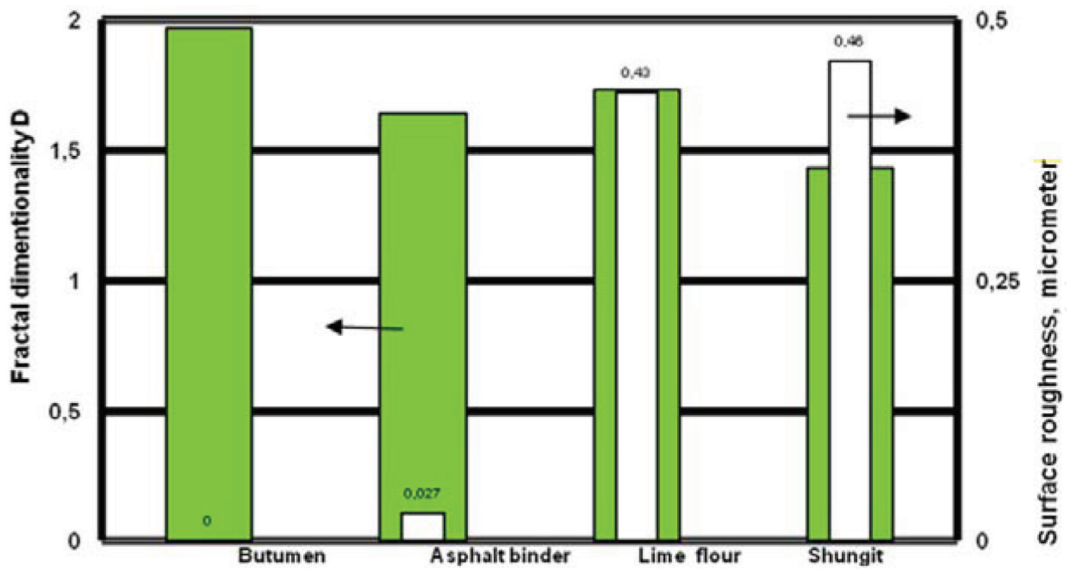

Figure 7. Correlation of the surface roughness and fractal dimensionality characteristics.

Thus the maximal degree of roughness of asphalt concrete binding agent with shungite is 0.027μm (the scan size is 5.0 × 5.0 μm). Fractal dimensionality of the surface is D = 1.64. Composite "bitumen-shungite" surface in 3D is presented in **Figure 5**.

The less surface roughness the nearer the value of surface fractal dimensionality to the criteria "2" that is the material is more dense and homogeneous. Composite "bitumen-lime stone" surface in 3D is given in **Figure 6.**

Correlation of the indicators of the surface roughness and fractal dimensionality characteristics is shown in **Figure 7**.

3. Comparison of reactive ability of shungite and lime stone powders during amalgamation with bitumen

Mineral powder together with bitumen form oriented bitumen layers on mineral grains. These oriented bitumen layers are developed in different degrees. These layers are followed by free bitumen. The qualitative structure of bitumen changes occur in oriented layer as a result of the adsorption processes and bitumen or its separate components diffusion deep into mineral material.

Adsorption is the concentration of substances on a surface or inside a solid body. Not less than two components take part in the process of adsorption.

The nature of such interaction is conditioned not only by the group bitumen structure but also by the properties of mineral powder, its chemical mineralogical composition, grains form, structural peculiarities and surface nature.

Active surface centers are on the surfaces of any mineral material. They condition their capacity of reaction and take part in the interaction with organic binding agent.

The presence of the active centers which can absorb practically all organic compounds existing in bitumen provides strong adhesion contacts between binding agents and mineral materials surface.

Chemisorptions are substances adsorption from the surrounding environment by liquid or solid body. It is accompanied by the formation of chemical linkages. Absorption is considered as a substance chemical adsorption by solid body surface that is as chemical adsorption. At chemisorptions there is a linkage formed between atoms (molecules) of adsorbent and adsorbate. Therefore, it can be considered as chemical reaction which is limited by surface layer.

Interaction of binding agents and mineral materials is the most fully appeared during chemisorptions processes taking place on the interface. Herewith the binding components diffuse into pores spaces of mineral materials and there is a physical adsorption of binding surface film which adheres to the stone materials.

In the very work, the reactive properties of the mineral material were considered according to the bitumen amount adsorbed from benzene solutions [9].

The amount of bitumen adsorption from benzene solutions on the surface of mineral powders was defined by the following method:

Bitumen solutions were prepared on the pure chemical nonpolar benzene of four different concentrations: 1, 3, 6, 9 g/l. Weights of tested powders of 5 g each were put into with ground-in stoppers glass flasks of 200 ml capacity and then they were covered with 50 cm^3 of benzene solutions of designed concentrations and agitated on a special plant for an hour.

After agitating, the flasks with the contents were left alone for 24 h. Then the part of the solution was taken out from the flasks and the bitumen concentration was determined by photometer KFK-3 (КФК-3).

The absorption was calculated by the formula:

$$A = \frac{(C_0 - C) \cdot V}{1000 \cdot m} \tag{1}$$

where

Co – initial concentration, kg/m^3;

C – equilibrium concentration, kg/m^3;

V – solution volume, m^3;

M – mineral powder mass, kg

The amount of bitumen chemically connected with the powder surface was defined according to the difference of adsorption and adsorbed bitumen values.

Desorption were conducted by the following method:

The powder left after measuring of adsorption value was covered by 50 sm^3 of pure benzene and agitated on a special plant for an hour. The flasks were left alone for 24 h. After that the samples were taken and the bitumen concentration was determined by photometer KFK-3 (КФК-3).

According to the amount of the powder left on the mineral powder surface, it is possible to reason about the powder surface activity.

The conducted experiment allows to estimate the adsorption properties of the under test mineral materials. The results of the investigations are given in the **Figure 8**.

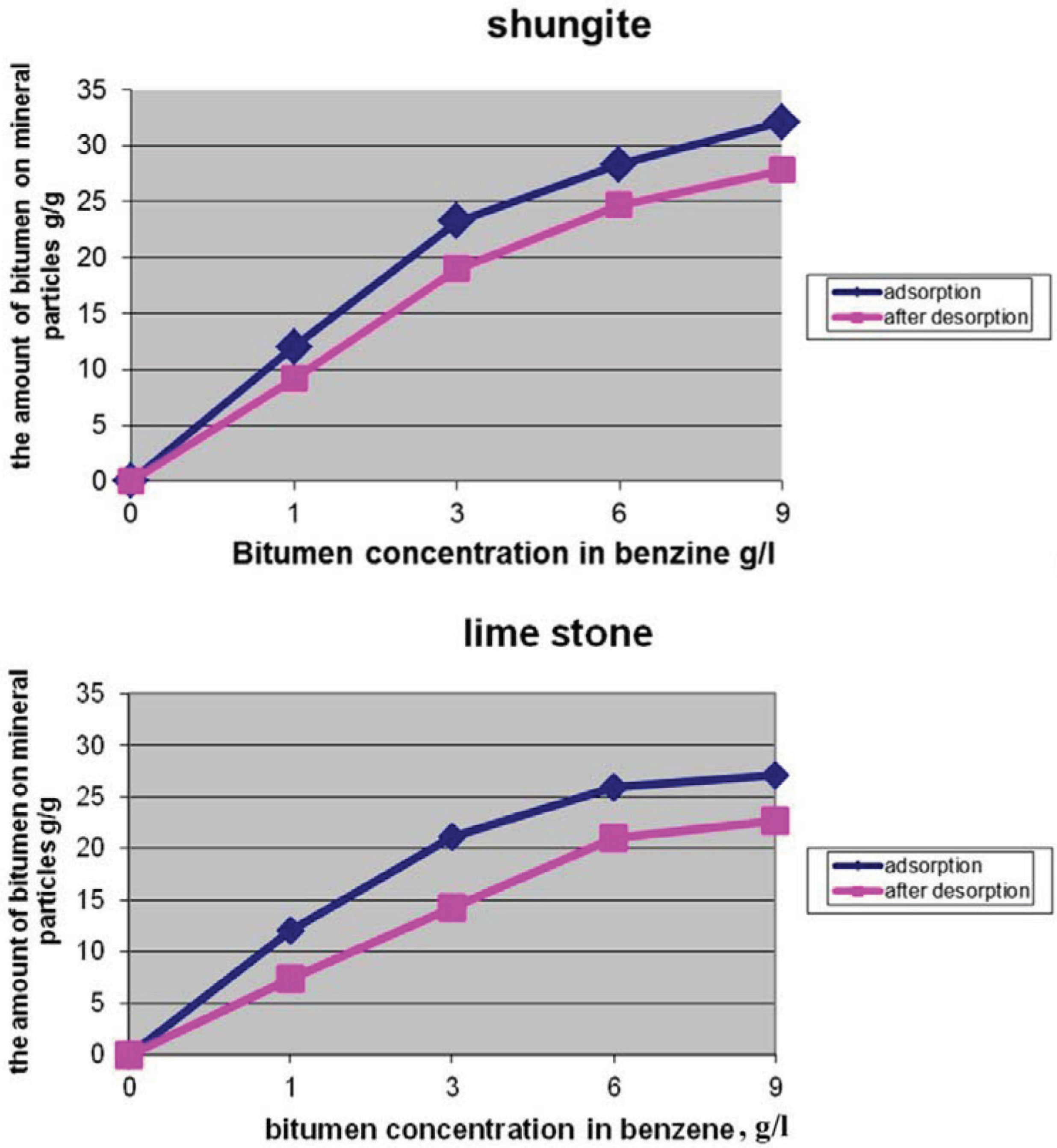

Figure 8. Adsorption–desorption of bitumen on shungite and lime stone surfaces on benzene solutions.

The bigger amount of bitumen is adsorbed on the shungite mineral powder surface than on the lime stone material surface. It was the same at the primary absorption and after the adsorption with benzene. For example, 19 g/g of bitumen are absorbed on shungite surface at bitumen concentration in benzene solution of 3 g/g but 14 g/g of bitumen are absorbed on a lime stone surface, respectively.

The influence of mineral powders on the bitumen structure changing after its desorption from the surface was researched by the spectroscopy method. This method allows investigating mechanism of powders interaction with bitumen, revealing the changes in its structure after adsorption on the mineral powder surface.

It was determined that after bitumen desorption from the shungite surface insignificant amount of organic compounds were left in binding agent. Therefore, they were adsorbed on the surface of shungite mineral powder while their great part on the surface of mineral powder from lime stone was desorbed with benzene. **Figure 8** demonstrate adsorption–desorption of bitumen on shungite and lime stone surfaces on benzene solutions.

The research results of bitumen adsorption and desorption on the surfaces of dispersed materials and bitumen infrared spectrums after the contact with mineral powders show that shungite mineral powder interacts with bitumen more actively than with the lime stone powder (**Figure 8**). The obtained results prove the formation of stable chemisorption bitumen bonds with shungite surface.

4. Infrared spectroscopy

During infrared radiation passing through the substance, the excitation of molecule oscillating movement or their separate fragments takes place. It is observed that the abatement of intensity of the light passed through the sample. The absorption is not in the whole spectrum of incident radiation but only at those wavelengths the energy of which relative to the energy of excitation of oscillations in the molecules under research. Therefore, the wavelengths (or frequency) at which there is maximal absorption of infrared radiation can indicate the presence of these or those functional groups or other fragments in the sample molecular.

5. Shungite mineral powder effect on the asphalt concrete structural-mechanical properties in time

The researchers studied theoretical and practical aspects of shungite mineral powder with account of its interaction with organic binding. The interaction of binding agent with mineral materials depends on chemisorptions processes on their interface. The strength of chemiadsorption bonds between bitumen and mineral powder depends not only on the chemical impact of the bitumen and mineral powder components but also on the mineral powder particles surface state, studied with the microscope (C3M) NanoEducator.

The higher shungite mineral powder porosity than limestone promotes the concentration of the considerable amount of resin in surface microspores. But some amount of oils penetrates the material because of the selective diffusion. That is why structured bitumen films on the shungite particles surface have strong cohesion with them.

Porous filler in shungite bitumen binding agent composition provides the lower temperature of the surface cracking. The tensile strength in such a composition is rather higher than the standard asphalt concrete tensile strength based on dense filler as the friction between the particles is higher due to the greater roughness and specific surface of shungite particles.

The presence of shungite bitumen binding agent in asphalt concrete mix allows increasing surface fracture strength. It is because the chemical activity of shungite particles after their pores filled with bitumen light fractions minimizes internal tension and improves thermal stability of the material.

Shungite particle porosity has better developed specific surface of different mix components as during dry mixing of mineral materials before their integration with bitumen the small mineral powder particles adhere to filler grains. At such processing, a mechanical "modification" of big grains surface which improve bitumen adhesion takes place with them.

Bitumen in thin layer on the mineral particles surface becomes structured, more dense and viscous changing its nature in time. That is why the nature of asphalt concrete mixes based on mineral powder from shungite was defined in different periods at samples conditioning in air: 2, 15, 30, 60 and 90 daily age. Changing of structural mechanical properties of asphalt concrete in time at t + 20°C is presented in **Figure 9**.

The analysis of received results allows determining the following:

in consequence of continuing processes of structure forming the compression strength limits of asphalt concrete based on shungite binding agent at t = 20° (**Figure 9**) and 50°C (**Figure 10**) increases in dependence on sample age conditioning in air. **Figure 10** shows the changing of asphalt concrete structural mechanical properties in time at t + 50°C.

The higher strength limit of asphalt concrete with mineral powder under compression at t = 20 and 50°C than standard asphalt concrete based on lime mineral powder indicates the higher

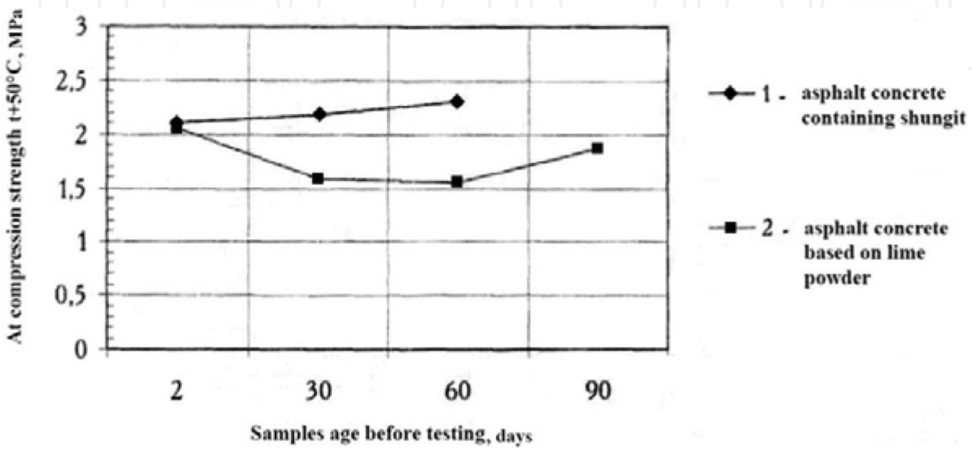

Figure 9. Changing of structural mechanical properties of asphalt concrete in time at t + 20°C.

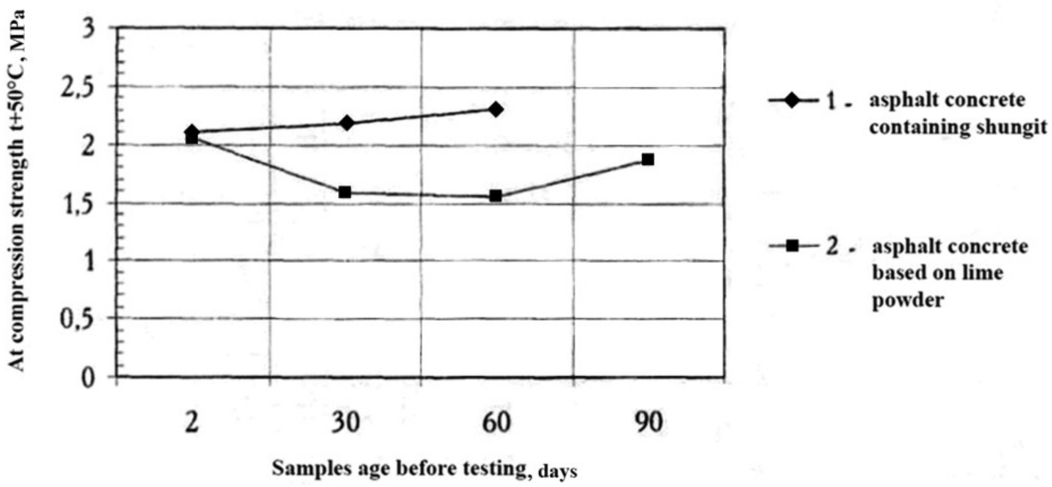

Figure 10. Changing of asphalt concrete structural mechanical properties in time at t + 50°C.

shear strength of asphalt concrete surfaces with shungite bitumen binding agent [4]. It has become usual that the asphalt concrete life service is considerably smaller than theoretically possible according to the abradability conditions. It shows the unconformity of structure – rheological performances of asphalt concrete and its operation conditions. Asphalt concrete during its life duration is affected by different factors: traffic loads, heating, cooling, humidification, and so on. But the normative documents recommend asphalt concrete designing only according to the strength in dependence on traffic load. The possibility of forming shear deformations on asphalt concrete surface in summer time or thermal cracks at negative temperatures is not considered. That is why the deformations excite premature surface destructions more often than the vehicle loads.

Asphalt concrete under different effects is elastic or elastic-viscous, or plastic substance. The theory of elasticity or the theory of plasticity describes only particular cases of asphalt concrete stress state and cannot create the full picture of asphalt concrete operation. Rheology describes asphalt concrete work in deflected mode more objectively.

In rheology, the possibility to describe the stress and deformation in time by differential equations appears. The sphere of these equations definition depends on conditions in which the given materials work. It is suggested that compositional viscous -elastic–plastic material has the total main properties: elasticity, viscosity and plasticity.

While differential equating the main material properties are shown as physically substantiated mechanical models, deformation laws of which are premeditated. In rheology, different simple and complicated models of physical bodies which should correspond to the differential equations situation are used.

While researching rheological characteristics of asphalt concrete based on mineral powders from shungite and limestone, the method by Boguslavsky [10] and Ya. N. Kovalyov was applied. For that target, the height *h* and the diameter *d* of asphalt concrete samples before and after the testing and the limit of compression strength were measured.

According to these data, the values of rheological parameters were calculated as follows:

Relaxation time:

$$\Theta = \frac{400 \cdot h \cdot \Delta h^2}{\Delta d^2} \tag{2}$$

Retardation time:

$$\tau = \frac{1000 \cdot \Delta d}{h} \tag{3}$$

Coefficient of elasticity:

$$K = \frac{R \cdot h}{\Delta h} \tag{4}$$

Viscose compliance coefficient:

$$\gamma = \frac{\tau}{K} \tag{5}$$

Viscose coefficient according to Mazwell' s equation:

$$\eta_m = \Theta \cdot K \tag{6}$$

Viscosity of undisturbed structure was defined by the formula.

$$\eta_m = \frac{400 \cdot R \cdot h_1^2 \cdot \Delta h}{\Delta d} \tag{7}$$

Water saturation duration, samples age and freezing cycle number influence rheological characteristics of asphalt concrete were investigated in the road laboratory.

The blanket from crushed stone-mastic mix with shungite mineral powder was constructed in order to satisfy the experiment and study physical-mechanical properties in real operation conditions. Before that, shungite mineral powder of gabbroic-diabase- crushed stone and crushed stone from gabbroic –diabase and bitumen were tested.

The additive based on cellulose filaments Viapor was used as stabilized additive preventing mix segregation and bitumen-shungite binding delimitation at high technologic temperatures. This additive increases the thickness of bitumen film on mineral particles. The mineral proportion of crushed stone-mastic asphalt concrete mix was matched during the research. The composition should provide as follows:

- shear resistance and rut forming resistance at high temperatures;
- water saturation of surface layers at small residual porosity.
- higher crack resistance at surface deformation and under mechanic effects from vehicles.
- high wear resistance.
- uneven surface texture and designed coefficient of adhesion;
- aging resistance.

For optimization of composition of crushed stone-mastic and shungite mineral powder, the specific peculiarities of them were considered.

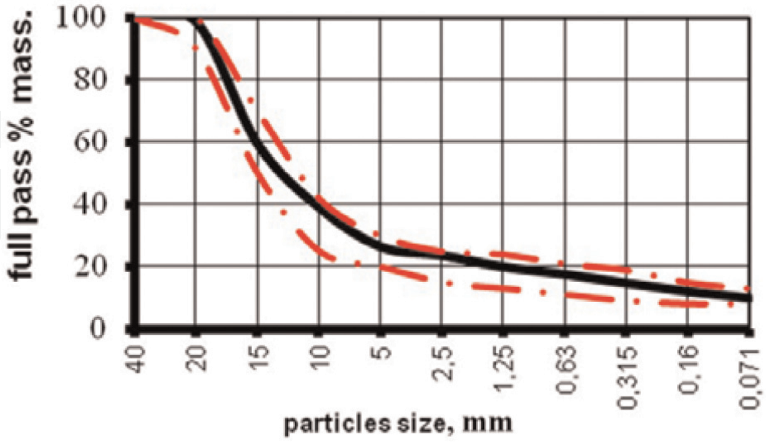

Figure 11. Grain proportion of mineral part of asphalt concrete.

Date of testing	Number of samples	Place of sampling	Layer thickness g(upper /lower) layer)	Surface samples			
			Fact.	Weight of dry sample, g	Weight of dry sample in 30 minutes of aging in water, g	Volume weight g/cm^3	Water saturation, % of volume
1	2	3	4	5	6	9	10
01.10.2011 (shungite mineral (powder)	1	1–1 (B)	5.0	572.20	576.93	2.53	2.36
		1–2 (B)	5.1	920.72	927.76	2.54	3.50
		1–3 (B)	5.0	972.90	976.12	2.58	2.11
	3	3–1 (B)	5.3	967.88	970.26	2.57	1.68
		3–2 (B)	5.8	973.60	976.79	2.57	1.26
		3–3 (B)	5.5	1169.82	1171.60	2.56	0.66
	4	4–1 (B)	5.0	902.55	905.24	2.58	1.01
		4–2 (B)	5.3	1041.18	1044.03	2.54	1.88
		4–3 (B)	5.1	879.19	884.64	2.54	3.10
01.10.2011 Lime stone mineral powder	5	5–1 (B)	5.1	868.72	871.10	2.59	1.66
		5–2 (B)	5.0	1152.31	1156.71	2.50	2.46
		5–3 (B)	5.0	871.29	872.98	2.56	1.79
	6	6–1 (B)	5.2	909.79	911.48	2.60	1.28
		6–2 (B)	5.7	1420.38	1422.85	2.56	0.81
		6–3 (B)	5.7	1363.83	1366.46	2.55	1.06

Table 2. Physical-mechanical indexes of asphalt-concrete from pilot and control sites.

Shungite	Shungite	Shungite	Shungite	Shungite	Lime stone	Lime stone	Lime stone	Lime stone	Lime stone
30.08.2011	19.10.2012	19.05.2012	03.10.2012	08.05.2013	30.08.2011	19.10.2012	19.05.2012	03.10.2012	08.05.2013
0.390	0.510				0.380	0.450			
0.420	0.560				0.420	0.400			
0.335	0.520				0.44	0.48			
0.382	0.53	0.451	0.389	0.365	0.413	0.443	0.401	0.325	0.309
0.333	0.5	0.437	0.361	0.338	0.379	0.398	0.359	0.315	0.246
0.43	0.56	0.466	0.418	0.393	0.448	0.489	0.443	0.335	0.372

Table 3. The dynamics of adhesion capacity on pilot and control sites.

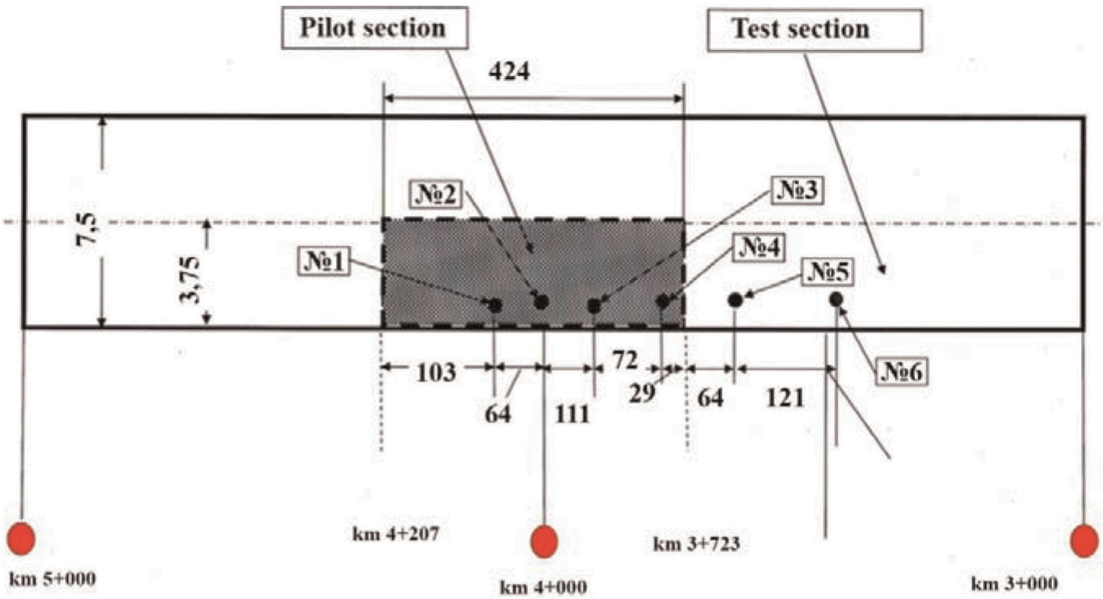

Figure 12. The diagram of sampling on pilot site.

The materials physical-mechanic properties which comply with demands of standard documents were used in asphalt concrete crushed stone-mastic composition.

Granularmetric proportion of crushed-stone asphalt-concrete is demonstrated in **Figure 11**.

After asphalt concrete paving on the pilot site, the blanket has been observed. The adhesion coefficient, evenness, rutting and physical-mechanical properties of asphalt concrete was defined. The results of physical-mechanical properties, adhesion indexes testing are in **Tables 2**, **3**, and the diagram of sampling is in **Figure 12**. Physical-mechanical indexes of asphalt-concrete from pilot and control sites are in **Table 2**.

There is the diagram of sampling on pilot site demonstrated in **Figure 12**.

The coefficient of adhesion is defined at the same time on the pilot site of crushed stone surface with shungite mineral powder and on the control site with lime stone mineral powder. The

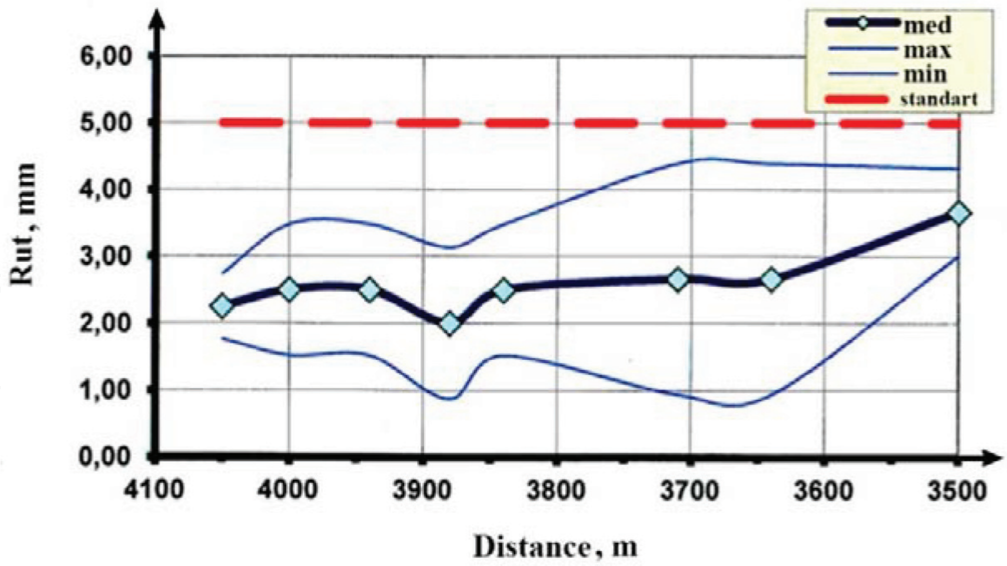

Figure 13. Ruts state on the site with shungite mineral power.

dynamics of adhesion capacity on pilot and control sites are given in **Table 3**, but the ruts state is demonstrated in **Figure 13**.

The monitoring for the state of crushed stone-mastic blanket shows that shungite containing asphalt concrete is in less degree rut prone in comparison with asphalt concrete on lime stone mineral powder.

6. The analysis of traffic load effect on a road blanket

The assessment and prediction of fatigue asphalt concrete properties are the actual problems in assurance of nonrigid road surface reliability.

The effect of fatigue is taken as a process of progressive material destruction by cracks. There are differed three forms of destruction: the beginning of cracks formation; the period of their stable growth and the stage of their intensive growth.

In comparison with the initial period of cracks formation which takes a significant time, the phase of stable cracks growth can be analyzed as the main fatigue process. Cyclic effect of moving vehicles (load) leads to the progressive cracks growing up to the critical depth. A crack increases spontaneously in the third stage which induces the fracture of the material. [11].

The analysis of fatigue performances based on the thermal fluctuation theory of fracture by S.N. Zhurkov shows that fatigue properties of asphalt concrete directly depends on the degree of the plasticity and there is a definite connection between strength and fatigue material properties. There are two different methods of fatigue tests [12]: the test with constant stress amplitude; the test with constant deformation amplitude.

The test of fatigue with constant deformation amplitude is more correct in comparison with the test with constant strain amplitude; as practically, it is not possible to determine the constant stress during the cracks growing and accordingly and the reduction of material area.

Asphalt concrete fatigue fracture in the blanket takes place as a result of cracks formation in the lower tension region and their constant diffusion onto the cover blanket surface. The number of repeated loads necessary for the cracks diffusion onto layer thickness exceeds the number of cycles before the appearance of the first fatigue crack in 20 times. Therefore, the asphalt concrete durability in a blanket exceeds the number of cycles "load-unload" without intervals in which asphalt concrete sample sustains up to fracture in the laboratory in 100 [12] or 200 [13] times.

Operation ability factors of asphalt concrete reliability can be divided into two groups: external and internal.

To the external factors we can refer the environment influence of three types: mechanical, physical-climatic and chemical; to the internal: the indexes of quality, determining the asphalt concrete ability to resist the mentioned types of external one.

The typical fatigue peculiarity is the following: the load factor which is less than the destructive one leads to the progressive durability and degradation of road surface.

Bearing capacity and operation durability of asphalt concrete blanket are more completely characterized by modulus of elasticity and tensile in bending strength.

Dynamic state of road blanket depends on traffic flow concentration and composition and also on the intervals between separate cars.

Traffic loads induce both deflections and oscillations in road blanket are conditioned by momentary elasticity and elastic deflection of road constructions.

While researching bitumen water resistance and adhesion to mineral powders in a laboratory it was proved that bitumen stresses exfoliation from the mineral material surface were comparatively small [14, 15]. In real operation conditions, the additional stresses appearing at traffic movement influence on the wet blanket exceed the thermodynamic ones. Practically, water presses into a blanket in front of the moving wheel and presses out from a blanket after a wheel. The results of such a pumping action are various and difficult for consideration.

At short-term contact of moving wheels with surface, the water pressure in pores of up to 0.05 cm radius is not enough for asphalt concrete fracture but for popcorn mixes it can reach destruction quantity.

If the prolong temperatures are >50°C the deformations of different types appear on an asphalt concrete blanket. The reason is the following: after heat accumulation in asphalt concrete layers, the degradation of bitumen viscosity takes place. According to the second law of thermodynamics (entropy), the grade of the temperature, concentration, barometric pressure always direct from the big value to small one. That is why bitumen starts to move upwards because its concentration is higher inside the asphalt concrete blanket than on the surface. Hereby there is its transition from structured state into the phase of free bitumen. The distance between the mineral material grains increases and the possibility of transmission as a result of wheel load application appears.

It was proved that the mechanism of accelerated fatigue fracture of water saturated asphalt concrete during surface under cyclic dynamic loads is conditioned in certain grade by the appearance of pulse hydrodynamic pressures in water saturated pores of between grains space. Experimental researches of fatigue properties of asphalt concrete while working in the water saturated state show that the service life before the fracture in water saturated state is shorter in 1.5–2.5 times in comparison with the asphalt concrete working in dry state [11, 16]. That is why the formation of pulse hydrodynamic pressures in pores of water saturated asphalt concrete under the moving cars dynamic loads is one of the main mechanisms of asphalt concrete fatigue in watering conditions [14].

7. Previous work reports of dynamic loads on fatigue properties of asphalt concrete

At the car speed of more than 30 km/h the surface load process at the reference point *d* during a small time interval can be represented as the static load *F* affecting on the definite blanket volume on the base under the harmonic vibrations. With account of the before mentioned assumption, the authors used the developed in the university (VGASU) method of the prediction of asphalt concrete operational properties based on the results of testing of the beams $4 \times 4 \times 16$ (cm) on the vibration exciter (**Figure 14**).

Vibration exciter provides the production of a frequency and vibrational amplitude from 10 up to 100 Hz and from 0.1 to 5 mm respectively gradually regulated during the operation time. The load onto the sample can change from 2 to 60 kg.

Figure 14. Vibration exciter at the moment of asphalt concrete beams testing.

Analytical dependences able to determine operation period duration under simulation load were taken as the base of method.

The vibrations similar to the harmonic form are modeled on a vibration exciter:

$$A = A_0 \sin(\omega t + \varphi_0) \tag{8}$$

where A – vibrational amplitude at the time moment t:

Ao – maximal amplitude;

φo – initial form.

$\omega = 2\pi f$ - cyclic frequency, where f – vibrational frequency of vibration exciter.

direction of the forces, effecting on asphalt concrete test beam in relaxation stage can be represented in **Figure 14** as:

where F1 – static load weight influencing the asphalt concrete beam.

F2 – elastic force in asphalt concrete beam;

F3 – inertial force during vibration exciter vibrations;

d – arbitrary point of load application.

The process of asphalt concrete fatigue fracture usually has three stages: internal fractures accumulation accompanied by a significant elasticity module reduction; microcracks appearing at small velocity of module elasticity reduction; propagation and progressive development of cracks with strong reduction of elasticity module [3].

The tension acting in the beam section in the bridge span center was calculated by the formula:

$$\sigma = \frac{3P_\partial l}{2bh^2} \tag{9}$$

where P_∂ - dynamic load; l – span between piers; b, h – section size. The value of the relative deformation was defined by the formula:

$$\varepsilon_m = \frac{(n_1 - n_2)}{Km} \cdot 5 \cdot 10^{-6} \tag{10}$$

where n1 и n2 - strain transducer registration for the sample without loading and vibration, and after the loading and vibration; K*m*– coefficient of strain-sensitivity of a strain transducer.

The values of relative deformation were defined by a strain transducer registrations should be close to the design ones received by the formula:

$$\varepsilon_p = \frac{6fh}{l^2} \tag{11}$$

At adherence to the situation $\varepsilon_p = \varepsilon_m$ the module of elasticity is defined by the formula:

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$$E_\partial = \sigma/\varepsilon_m \tag{12}$$

$$\sigma = \frac{3Pl\left(g + 4A_0\pi^2 f^2\right)}{2bh^2} \tag{13}$$

The final formula for dynamic module of elasticity determination is written down as:

$$E_\partial = \frac{3Pl\left(g + 4A_0\pi^2 f^2\right)K_m}{2bh^2(n_1 - n_2)\cdot 5\cdot 10^{-6}} \tag{14}$$

The assessment of operation reliability caused by operating –climatic effect (T) is implemented by the formula:

$$T = \frac{N_p}{N_Э} \tag{15}$$

where Np - number of asphalt concrete loading cycles up to its dynamic elasticity module abatement in two times; design number of wheels loading application during the year of road blanket service.

$$N_Э = N_{np}K_1K_2 \tag{16}$$

where N_{np} – equated movement intensity; K_1 – coefficient of a car track overlapping; K_2 – coefficient considering portion of design cars in a flow (0.3–0.4).

For the investigation of asphalt concrete cyclic fatigue in a laboratory, the following factors were taken: asphalt concrete water saturation as physical-climatic; aging after heating during 5 h at t 150°C as chemical; asphalt concrete composition formula as internal ones.

Cyclic fatigue under dynamic loads is tested on the specially constructed diagnostic tester in the laboratory providing load application with frequency of 868 min^{-1} in the regime of cyclic bending of the 2.5 × 4 × 16 cm size test beams at the fixed deformation amplitude. The test temperature is 20°C. The fatigue deformation amplitude was registered by the moment of destruction. The deformation amplitude while testing was 0.0021 (the test beam kink was equal to zero).

The use of shungite powder instead of standard mineral powder promotes the growth of asphalt concrete fatigue life especially in the conditions of asphalt concrete water saturation. It may be connected with the higher adhesion of shungite powder.

One of the important properties of asphalt concrete predetermining its durability (during the destruction) is its structural stability in the changing humidity regime and temperature conditions. At water saturation adsorption aqueous layers simplify the formation of new surfaces in asphalt concrete during its deformation reducing the surface energy (Rehbinder's effect). Wedge effect of aqueous layers separating mineral grains and exfoliating bitumen strengthens the destruction effect. The mechanism of accelerated fatigue destruction of water saturated asphalt concrete at surface operation in the regime of cyclic dynamic loads is conditioned by the appearance of hydrodynamic pulsations in filled with water porous. This fact was investigated by Rudensky [17].

Asphalt concrete composition	Aging (Thermal effect)	Number of destruction cycles	
		dry	Water saturated
Granit sieving – 92%, lime-stone mineral powder −8%, bitumen of road oil asphalt 60/90–7.5%	Without heating	14,756	10,416
	After 5 h of heating	17,707	11,488
Granit sieving –92%, shungite mineral powder – 8%, road oil asphalt 60/90–7,	Without heating	17,757	14,322
	After 5 h of heating	20,092	16,297

Table 4. Values of fatigue durability of asphalt concrete samples.

The assessment of asphalt concrete by the method of dynamic effect on the water saturated samples is more corresponding to the operation conditions of the material in road construction than the known methods based on statistic water action. That is why the tests of comparison fatigue of asphalt concrete durability were conducted on dry and water saturated samples. Water saturation of asphalt concrete samples was 1.65–1.66% by volume. Values of fatigue durability of asphalt concrete samples were given in **Table 4**.

The application of shungite material instead of the lime stone mineral powder promotes the growth of asphalt concrete fatigue durability especially in the conditions of water saturation. It connects with high adhesion activity of shungite carbon with shungite carbon containing material [21].

The increase of asphalt concrete fatigue durability with the application of shungite mineral powder as a result of aging (after the heating for 5 h) demonstrates the properties stability under temperature effect. It is clear that it connects with oil migration from pores in carbon containing materials and bitumen film rejuvenation during aging.

8. Asphalt concrete bindings effect

An important structure unit of asphalt concrete that is asphalt concrete binding is generated while mixing mineral filler with organic binding. The nature of asphalt concrete is determined by the quality of the asphalt concrete binding. The properties of the system "bitumen-mineral powder" depend on the properties of binding, chemical-mineral composition and mineral filler dispersion, and also these components proportions [18].

The interaction of bitumen with mineral powder is conditioned not only by the rather developed specific filler surface but also by internal grain surface generated by the branched microspores system. Porous fine dispersed fillers cause strong structuralized influence than dense ones. Micropores differ by the high adsorption potential due to which the significant part of surface active components of bitumen sorbs in them. Therefore, it is possible to suggest that porous mineral fillers will cause strong structuralized influence on bitumen than the traditional materials. It is clear that the interest to porous fillers in asphalt concrete composition is conditioned by this.

Mineral powder from shungite (Medvezhjegorskoe deposit) differs from the traditional one from dolomite by bigger porosity of the surface and high developed micropores system and also bitumen of the grade БНД 60/90 of Ryazan НПЗ was investigated. The dispersed raw under study will be correct to test for accordance with the demands [5] asphalt concrete mixes mineral powders. Characteristics of under research fillers properties are shown in **Table 5**.

Mineral powder meets the requirements. But the porosity of the material 20–25% higher than the porosity of lime stone filler and the value of specific surface at the same grain metric proportion is 60–70% higher. So the conclusion is the system of micropores of under research carbon containing raw material is more developed.

The results of the experimental researches of asphalt concrete binding agent. From our point the most informative method of studying the method "bitumen-mineral powder" is the investigation of asphalt concrete binding agent characterized by greater homogeneity of the structure and stability of the properties. Asphalt concrete binding agent was produced from according to the standard method with the before bitumen amount batching. Thus for the mineral powder from shungite the index is 16.2% which is 26% more than traditional lime stone mineral powder has. These data are correlated with the indexes of bitumen proportion in powders. The research results of the physical chemical properties of asphalt concrete binding agent with optimal amount of bitumen are given in **Table 6**.

Coefficient of composite thermal stability and its water resistance are the most interesting among all the data. Therefore, the index of heat resistance of shungite is 14.3% more than while using the traditional mineral powder from lime stone or dolomite. Thermal resistance of mixes and asphalt concrete is characterized by the coefficient of thermal resistance defined as the ratio of ultimate compression strength at t-20°C to the ultimate stress limit at t = 50°C.

As the under research, raw material is porous; the water can penetrate inside the shungite grains and decompose the asphalt concrete binding agent on the bitumen- mineral powder interface if binding agent covers mineral powder surface partially or if the adhesion bonds are weak.

Names of the characteristics	Mineral powder МП-2	Demands of the standard
	shungite	
Grain proportion, % on mass: Smaller 1.25 mm <0.315 mm <0.071 mm	100 98 80	Not less than 95 from 80 to 95 not less 60
Porosity, %	37	Not more 40
Indexes bitumen capacity, g	48	Not more 80
Humidity, % on mass	0.55	Not more 2.5

Table 5. Characteristics of under research illers properties.

Name of the index	Mineral powder МП-2	Requirements of established order
	shungite	
Compression strength, M Па: при		
20°C		
20°C in water saturated condition 50°C	4.3	
3.9		
2.7	—	
Water saturation of samples from powder and bitumen mix	0.9	Not less than 0.7
Swelling of samples from powder and bitumen mix, %	1.87	Not more than 3.0
Coefficient of heat resistance	0.63	—

Table 6. Physical chemical properties of asphalt binding agent.

9. Research of structuralized processes in asphalt concrete

The growth of the strength of the samples from shungite is 9.3% compared with the analogical indexes on lime stone [6, 15]. At less density, the growth of strength characteristics in time which attests the process of structurization of asphalt concrete on shungite mineral powder takes place.

This process can be explained from the point of active extraction of bitumen components with mineral powder from shungite. While analyzing the structure of asphalt concrete agent by microscope (C3M) NanoEducator at increase in 1000 and 2000 times (**Figure 15**), it is possible to mention the substance structure vagueness. The following figure present microstructure of asphalt concrete binding agent from (a) shungite (b) lime stone.

It is clear that an original solution of shungite occurs during amalgamation of binder and shungite. Modern image about the material under study is the precondition for such a supposition. It is known that shungite substance is not a simple amorphous carbon but a mix of various carbonic allotropes which have small lattices connected with amorphous carbon [20]. The more so various mixes of compound organic substances are a part of shungite composition. It is 97–99% of water saturated organics of shungite which escapes into the solution together with fullerenes and determine their properties.

Chemical composition of mineral powders from shungite and lime stone is shown in **Table 7**.

10. Conclusions

1. Experimental researches of physical-mechanical properties of asphalt concrete mixes of different types proved the possibility mineral powder from shungite application. So the interaction of bitumen with shungite mineral powder provides the formation of a stable structure of asphalt concrete with the predominance of closed pores.

2. The results of investigation of shungite mineral powder on scan prob. microscope with nanodementional resolution demonstrate the ability of shungite with high adsorption activity in comparison with organic binding promotes its structurization. Together with bitumen it forms the structured dispersed system acting as a binding material in concrete.

3. It is determined that at the result of shungite mineral powder application asphalt concrete has better water resistance and long water saturation properties which provides high corrosion resistance of asphalt concrete carpet in comparison with traditional powder from lime stone rock.

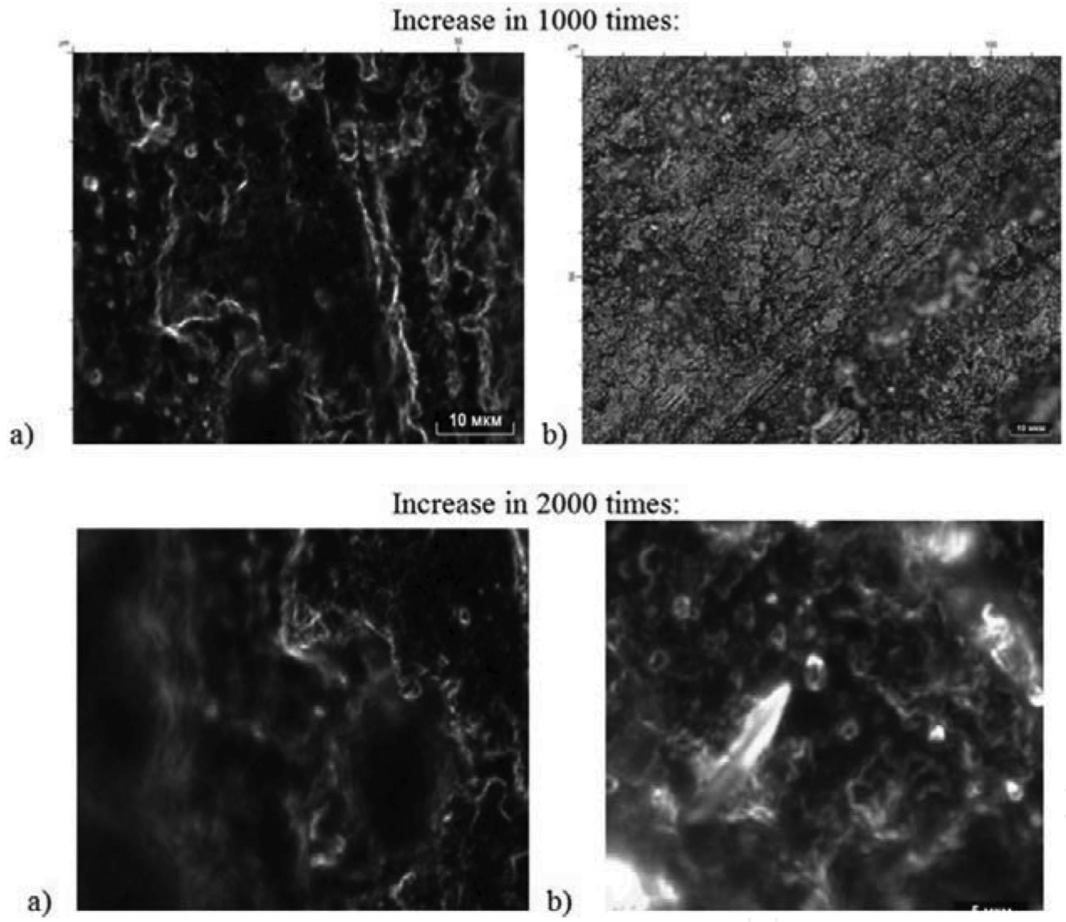

Figure 15. Microstructure of asphalt concrete binding agent from a) shungite b) from lime stone.

Sample	Mass portion, %			
	SiO_2	Al_2O_3	Fe_2O_3	Fe_2O_3
1 (shungite)	45.5	2.3	1.9	1.0
2 (lime stone)	2.1	0.1	1.2	0.8

Table 7. Chemical composition of mineral powders from shungite and lime stone.

4. The use of shungite material instead of lime-stone mineral powder increases the fatigue durability of asphalt concrete especially in the water saturation condition. It connects with the high adhesion activity of shungite carbon containing material.

5. During the process of plot arrangement it was determined that asphalt concrete mix has good placeability and compactability which allows promote designed characteristics of evenness and compacting factor while constructing road carpets.

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