

# Stabilizing Highly Dispersed Porous Mineral-Based Additives for Macadam Mastic Asphalt Concrete

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**Abstract –** The article analyzes research prospects of porous powder mineral materials for stabilizing additives used for macadam mastic asphalt concrete mixtures. The interaction of finely dispersed crushed claydite powder with a bituminous binder was studied. Efficiency of the use of expanded clay powder as a stabilizing additive for macadam mastic asphalt concrete was identified. It was revealed that modification of MMAC with expanded clay powder increases strength properties, heat resistance and water resistance of a bituminous mineral material. The effect of highly dispersed porous mineral powder on a steady increase in crack resistance, frost resistance and shear resistance of MMAC was identified. While studying rheological characteristics of crushed stone-mastic asphalt concrete, it was revealed that the structure of the modified MMAC provides maximum rigidity, triaxial compression and shear, maximum flexibility and high deformability of the coating of the material under tension.

**Keywords –** *macadam-mastic asphalt concrete; expanded clay powder; stabilizing additive; road pavements; asphalt binder.*

## I. INTRODUCTION

One of the most promising materials for road paving is macadam mastic asphalt concrete (MMAC). MMAC has the following important advantages in comparison with traditional dense asphalt concrete: increased water resistance, crack resistance, shear resistance and heat resistance, high wear resistance and aging resistance. MMAC mixtures are

characterized by a high content of bitumen and fractionated crushed stone (about 70-80% by weight) which should have an improved (mainly cubic) grain shape to create the most stable frame in the compacted layer of the coating. Large crushed stone forms a rigid frame structure of the material which ensures the effective transfer of loads to the underlying layers of the pavement.

MMAC mixtures are prepared and transported to the place of paving at elevated temperatures (about 160-170 °C. Paving is carried out at 145-150 °C. At such high temperatures, a high content of bitumen causes inevitable stratification of the mixture and the flow of the stone mineral material. In addition, there are prerequisites for bitumen stains and rutting which reduces the strength, shear stability of road pavements and reduces the time between road repairs. In these conditions, stabilizing additives are used to ensure homogeneity of MMAC mixtures and prevent negative processes described above.

Materials used for producing stabilizing additives are based on cellulose, asbestos, rubber, and polymers. Cellulose-based additives are among the most demanded (about 90% of all additives used). They are produced as fibers (TECHOCEL) and granules (Viatop, GENICEL, TOPCEL). Asbestos-based granules, rubber modifiers, high-strength acrylic fiber-based modifiers are used as well. Most of the stabilizing additives are imported. The high cost of additives actualizes the search for

new, effective and inexpensive stabilizers to reduce the binder run-off.

Russian and foreign scientists are studying additives that reduce runoff (B) and improve the quality of macadam-mastic asphalt concrete mixes. Currently, to reduce the cost of macadam-mastic asphalt mixes, various industrial waste is added into their compositions [1–4]. [5, 6] suggest using industrial fiber waste or cardboard as stabilizing additives for MMAC. There is a large number of publications on the use of rubber-based stabilizing additives and various polymers for modifying the bitumen binder MMAC [7, 8], etc. There are a number of papers which suggest ways to improve MMAC properties [9, 10].

Bituminous mineral compositions with highly porous fine mineral powders are of particular interest. According to the experimental studies, the use of porous powders based on expanded clay, perlite, vermiculite in bitumen-mineral compositions increases the number of physical, mechanical and operational properties. Thus, [11] analyzes the effect of porous fillers on the properties of asphalt binders. The influence of porosity of mineral powders on their structuring ability was revealed, and efficiency of porous mineral powders with a high content of acid sites to create dense asphalt concrete structures was identified. [12, 13] study a bituminous binder modified with exfoliated vermiculite and volcanic ash. The results indicate that the asphalt binder increases heat and crack resistance. Expanded vermiculite allows it to obtain a binder with an extended plasticity interval.

The analysis of these works suggests that the use of fine porous mineral materials in the composition of macadam asphalt concrete mixtures can have a positive effect on the properties of asphalt binder and increase the segregation stability of MMAC mixtures, physical and mechanical properties of MMAC.

## II. METHODS AND MATERIALS

This article studies the influence of finely dispersed expanded clay powder on the structure and properties of asphalt binders for macadam asphalt concrete mixtures, technological parameters of MMAC mixtures, physical and mechanical MMAC indicators.

The following materials were used: cubic crushed stone from dense rocks, sand from crushing screenings, activated mineral powder, BND 60/90 oil road bitumen, standard stabilizing additives Viatop-66, expanded clay powder. Highly dispersed claydite powder was produced by grinding clay brand 600 in a laboratory ball mill by selecting fractions less than 0.16 mm. The properties of expanded clay powder are as follows: specific gravity - 2.57 g / cm<sup>3</sup>, specific surface area - 5280 cm<sup>2</sup> / g, bulk density - 0.88 g / cm<sup>3</sup>, porosity - 36%.

The effect of haydite powder on the properties of asphalt binders was evaluated by changing penetration indicators and softening temperatures of the bitumen-based asphalt binder, activated limestone mineral powder and claydite powder (at their optimum ratio), and comparing with the properties of asphalt binding with a standard filler (activated limestone mineral powder) (Table I).

Possibilities of using highly dispersed screenings for crushing of expanded clay as a stabilizing additive as well as determining their influence on the MMAC properties were studied. Mixtures of MMAC-15 (Table II) modified with claydite powder which was introduced in the optimal amount into the MMAC were prepared. For comparison, samples of MMAC-15 were tested using standard stabilizing additives Viatop-66 (Table II). MMAC samples were tested in accordance with GOST R 31015-2002 and GOST 12801-98.

In order to identify features of the stress-strain state of the MMAC at different operating temperatures, rheological studies were carried out (according to the well-known method by Kovalev). Cylindrical samples of MMAC-15 with dimensions of 71.5 × 71.5 mm modified with expanded clay powder were tested. For comparison, standard MMAC samples with a stabilizing additive Viatop-66 were tested. Samples were subjected to compression tests at various temperatures. To calculate the rheological characteristics, geometric parameters of the samples (height and diameter) were measured before and after the test, and the compressive strength was recorded. The speed of movement of the press plate was v = 0.05 cm / s.

The following rheological parameters of the MMAC were determined: viscosity coefficient  $\eta_M$ , relaxation time  $\theta$ , retardation time  $\tau$ , elastic moduli E. The test results are presented in Table III.

## III. RESULTS

The test results for the influence of expanded clay powder on the properties of asphalt binders are presented in Table I.

According to the data (Table I), addition of highly dispersed expanded clay powder decreases the penetration index and increases the softening temperature. This is due to increased viscosity and heat resistance of the binder which can have a positive effect on reducing the flowability of bitumen in MMAC.

The decisive factor affecting the increase in viscosity of the asphalt binder based on highly porous fillers is selective filtration of the light components of the bituminous binder (oils, aromatic hydrocarbons) into micropore-sized mineral pores.

TABLE I. PROPERTIES OF ASPHALT-BINDING MATERIALS

Name of bitumen indicator	Asphalt Binding MMAC	
	Bitumen BND 60/90, activated limestone mineral powder	BND 60/90 bitumen, activated limestone mineral powder, modified with expanded clay powder
The depth of penetration of the needle, 0.1 mm: at 0 °C at 20 °C	20 51	20 43
Softening temperature according to the "Ring and Ball" method, °C	68.5	77.4

As a result of selective filtration, there is a structural change in the organic binder, a change in the Compositiona, and the number of compounds of bitumen different in molecular weight

and reactivity. Selective filtration increases concentration of active components of bitumen, such as asphaltenes and resins, as well as the most active compounds: asphaltogenic acids and their anhydrides. This determines the change in the structure and properties of bitumen and asphalt binder, increasing physicochemical and chemical activity at the interface between the bitumen and mineral material. In addition, the increased specific surface area and porosity of claydite powder can contribute to high sorption capacity.

The test results for physicomechanical and performance properties of the MMAC are presented in Table II.

It was established that porosity of the mineral part, residual porosity and the water saturation comply with the GOST. Water saturation W of MMAC modified with expanded clay powder characterizing open porosity of the material is slightly higher than the standard Composition. It also meets regulatory requirements.

Water resistance was estimated by water resistance coefficients  $k_v$  and water resistance coefficients under long-term water saturation  $k_{wR}$ . The MMAC water resistance indicators with the additive (Table II) significantly exceed those for the MMAC with Viatop-66. The increase in water resistance is positively affected by the higher modulus mineral aggregate in the MMAC Composition.

The use of expanded clay powder has a positive effect on stability of MMAC mixtures. Indicators of flowability (B) of the modified mixtures comply with the requirements of the standard.

By analyzing the data obtained (Table II), it should be noted that addition of expanded clay powder in MMAC mixtures increases their strength ( $R_{20}$ ) and heat resistance ( $R_{50}$ ). There are increased indicators of crack resistance and shear resistance of modified MMAC due to physicochemical interaction of the organic binder with a porous material. Improved crack resistance of MMAC is affected by a slight decrease in internal thermal stresses as a result of the use of porous powder materials.

Modified MMAC of the higher modulus coarse mineral aggregate provides a higher resistance to shear deformations of the resulting coating, which is reflected in an increase in the coefficient of internal friction and the rate of adhesion during shear.

The results of the rheological tests are presented in Table III. MMAC-15 modified with expanded clay powder has lower viscosity and less stress relaxation time than Compositions with Viatop-66. Consequently, at negative temperatures, the modified Compositions are more deformable, less brittle and more crack resistant.

At high operating temperatures, viscosity of the MMAC-15 modified with expanded clay powder is higher than that of the standard Composition MMAC-15. With increasing viscosity of asphalt concrete, its heat resistance and shear resistance increase. The relaxation time of stresses of modified MMACs is higher than that of standard Compositions; therefore, at high operating temperatures, probability of plastic deformations decreases.

TABLE II. PROPERTIES OF THE MMAC

Name of the indicator	MMAC-15 modified with claydite powder	MMAC-15 with Viatop-66	The value of the indicator according to GOST 31015-2002
Porosity of the mineral part, %	16	15.8	15-19
Residual porosity, %	3.1	2.9	2.0-4.5
Water saturation, W, %	1.94	1.85	1.5-4.0
Water resistance coefficient, $k_v$	0.99	0.96	$\geq 0.9$
Coefficient of water resistance with prolonged water saturation, $k_{wR}$	0.86	0.76	$\geq 0.75$
Indicator of the binder runoff, B, %:	0.13	0.11	$\leq 0.2$
Tensile strength at splitting at 0 °C, $R_p$ MPa:	6.18	5.69	3.0-6.5
Internal friction coefficient, $tg\varphi$	0.97	0.94	$\geq 0.94$
Shear clutch at 50 °C, $C_{50}$ MPa,	0.28	0.21	$\geq 0.2$
Compressive strength, MPa: at 20 °C, $R_{20}$ at 50 °C, $R_{50}$	4.97 2.1	4.3 1.68	$\geq 2.5$ $\geq 0.7$

TABLE III. RHEOLOGICAL PARAMETERS OF THE MMAC

Type mixture	$T, ^\circ\text{C}$	$\eta_*, (\text{H}\cdot\text{s}/\text{cm}^2)\cdot 10^6$	$\theta, \text{c}$	$\tau, \text{c}$	$E, \text{MPa}$
Composition № 1 Composition № 2	-10	183.87	9511.94	21.2	298.43
		145.53	6543.75	28.57	310.67
Composition № 1 Composition № 2	0	134.85	6769.23	24.53	214.06
		126.82	6299.77	27.97	226.25
Composition № 1 Composition № 2	20	37.37	5605.6	35.56	64.8
		47.67	5766.35	36.36	70.42
Composition № 1 Composition № 2	35	14.24	3473.89	40.54	40.99
		22.07	4481.28	38.22	49.25
Composition № 1 Composition № 2	50	5.0	2820.0	62.9	20.0
		6.18	3558.7	64.34	20.7
Composition № 1 Composition № 2	60	4.72	2491.4	47.18	13.26
		5.45	2985.7	49.65	19.33

a. Composition № 1 – MMAC-15 with Viatop-66

b. Composition № 2 – MMAC-15 modified with claydite powder

The change in the structure of MMAC due to the introduction of expanded clay powder, improves structural and mechanical characteristics of the material, increases the elastic

modulus  $E$  and decreases MMAC deformability at operating temperatures.

#### IV. CONCLUSION

The use of expanded clay powder in MMAC mixtures allows for absorption of the asphaltic binder which makes it possible to use the material as a stabilizing additive.

Studies of physicomechanical and operational properties of MMAC showed that the use of expanded clay powder in the Composition of the MMAC mixture improves strength, heat resistance and water resistance. The presence of highly dispersed screenings for crushing a porous filler reduces the internal temperature stresses of the pavement material and increases crack resistance and frost resistance.

Analysis of studies of the rheological characteristics of MMAC revealed that at negative operating temperatures, MMAC modified with claydite powder, have a higher crack resistance value and a lower brittleness value compared to standard MMAC with Viatop-66; at high operating temperatures, they have an increased shear resistance, heat resistance and resistance to plastic deformations. Thus, the following conclusion can be drawn: the structure of the modified MMACs, depending on the stress-strain state, combines maximum stiffness under triaxial compression and shear and maximum compliance and high deformability under tension. These rheological properties of asphalt concrete are especially important for ensuring shear stability, crack resistance and durability of road pavements under the real stress-strain state of the structural layers of road pavements.

In addition, one of the important aspects is substitution of expensive foreign stabilizing additives which can reduce the cost of MMAC mixes and contribute to the import substitution strategy.

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