DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

UDC 625.084

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A STUDY OF TEMPERATURE MODES AND STRENGTH CHARACTERISTICS OF STONE-MASTIC ASPHALT

Statement of the problem. An increasing use of stone-mastic asphalt and lack of detailed technology of the device of covering of this material is a problem faced by road industry institutions. Therefore there was a need to study the temperature and strength characteristics of stone-mastic asphalts in order to develop the technology of the device of asphalt concrete coverings of stone-mastic asphalts.

Results. In the present paper, an attempt is made based on the experimental data to establish the links between the limits of strength and temperature of stone-mastic asphalts, as well as the influence of the thickness of a layer on the tensile strength. The dependencies of the temperature of the mixture and strength characteristics during compression and shear are presented.

Conclusions. A lower temperature limit of the effective impact of the load on the sealing layer of coating was experimentally determined. The dependencies of the temperature of the mixture and physic-mechanical characteristics of stone-mastic asphalts-10, of stone-mastic asphalts-15, of stone-mastic asphalts-20 were obtained. The obtained data can be used in the calculation of the parameters of the technology of laying and compaction of asphalt coatings with the application of stone-mastic asphalts.

Keywords: stone-mastic asphalt concrete, tensile strength, technology, temperature, laying technology.

Introduction

Growing transportation in this country causes an increasingly heavy traffic with larger axial loads on road surfaces. In order to provide for traffic safety, there are growing demands for transportation and operation of roadways which are to be met in the construction process.

A growing transportation capacity of vehicles causes a reduction in transportation costs but results in larger loads on road surfaces thus resulting in failure and destruction of road surfaces, lower transportation and operation performance of roadways and there arises a need for extra investments for keeping the roadways in an orderly condition. Stone-mastic asphalt concrete mixes are increasingly used in road surface construction. The above trends in the development of transportation network cause new demands for the performance of asphalt concrete surfaces which is due to new road construction being used and new and improved technologies being introduced into the construction of non-rigid surfaces.

Stone-mastic asphalt is one of the varieties of hot asphalt. Unlike hot asphalt mixes with from 60 % stone of the total mass, stone-mastic asphalt contains 70…80 % of stone with an improved cube-like grains which gives rise to the strength of the carcass when a surface is compacted. A higher percentage of a binding material (from 5.5% to 7.5% of the total mass) and mineral powder (8…15 %) accounts for fewer empty spaces in the compacted layer of the surface. Short-wave mineral powder and 0.5-1.9 mm cellulose fiber is often used for stabilization [1]. This type of asphalt concrete has a better shear resistance, waterproof and roughness protection performance. According to the guidelines, stone-asphalt concrete is used in a 20-40mm layer which is most likely to undergo destruction. Highway construction practices suggest that it is also used for surface layers of up to 60mm [2].

The existing technologies of surfacing stone-asphalt concrete make use of the previous experiences of highway construction using hot asphalt mixes with no consideration of the parameters of stone-asphalt concrete mixes [6].

1. Determining the temperature of the end of the effective load effect on the compacted surface layer

The guidelines provide for the use of different types of materials and appropriate temperature of making and laying stone-asphalt concrete mixes. The analysis of the temperatures for stone-asphalt concrete mixes showed that the suggested values are higher for hot asphalt mixes. The suggested temperature at the end of laying stone-asphalt concrete mixes was not scientifically proven and ranges from 120 to 60 ºC, which affects the quality of compaction and organization of the works. The analysis of the existing guidelines on laying and compaction temperatures of stone-asphalt concrete mixes showed that the compaction depends on the type of bitumen and ranges from 175…140 ºC. In terms of organizing the works and providing the compaction parameters, the important parameter is the effective temperature of the end of compaction which provides high parameters of the compaction of the layer. The existing wide range of numerical values of the temperatures of the end of compaction of stone-asphalt concrete mixes (120…60 ºC) requires a comprehensive approach to this parameter [2, 3]. The attained density of the material under a cyclic load is known to depend not only on contact strains but also on the time. Using the standard methods for determining the strength limit of asphalt concrete, the required time for making a sample with a specified density in different temperatures of stone-asphalt concrete mix was identified. The results are in Fig. 1.

Each point in the graph is a mean value of the obtained results in the tests of 3 samples. They suggest that as the temperature of the hot mix drops to 110 °C, it takes more time to reach the specified density. In the temperature range of 170…110 °C the required time to reach the specified temperature remains the same. Based on it, we conclude that the minimum temperature of the effective compaction of a hot stone-asphalt concrete mix is in the range of 110…115 °C. It was also found that a change in the thickness of a layer and type of a stone-asphalt concrete mix does not influence the type of a dependence. The temperature of the effective end of compaction of stone-asphalt concrete mix is thus higher than for hot asphalt concrete mixes. Compare the temperature of the end of effective compaction of hot asphalt concrete with БНД bitumen 60/90 is 85…90 ºC.

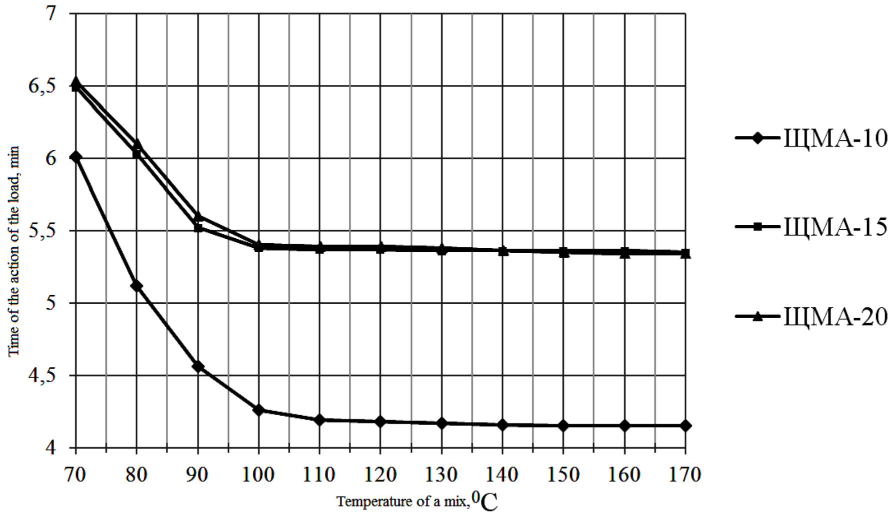


Fig. 1. Load-temperature dependence to achieve the required strength of asphalt concrete: stone-asphalt concrete mix -10, stone-asphalt concrete mix -15, stone-asphalt concrete mix -20, *h* = 70 mm, *D* = 70 mm, *P* = 40 MPa, *S* = 3 mm/min, БНД bitumen 60/90

2. Effect of the thickness of the laid layer on the deformation and strength characteristics of stone-asphalt concrete mix

Depending on construction parameters of road surfaces, the thickness of a laid layer of the material can vary. The guidelines provide for compression strength limits for hot asphalt mixes the materials used are to conform to. Considering the type of a mix, the sizes of kerns are different but the height of a sample equals its diameter. In order to make the effect of the thickness of a layer on the compression strength limit more clear, samples of varying height were made (Fig. 2).

Fig. 2. Stone-asphalt concrete mix samples for defining the effect of the thickness of a road surface layer on the strength parameters

The results suggest that the thickness of a layer influences the strength characteristics of road surfaces. The obtained results are in Fig. 3—5.

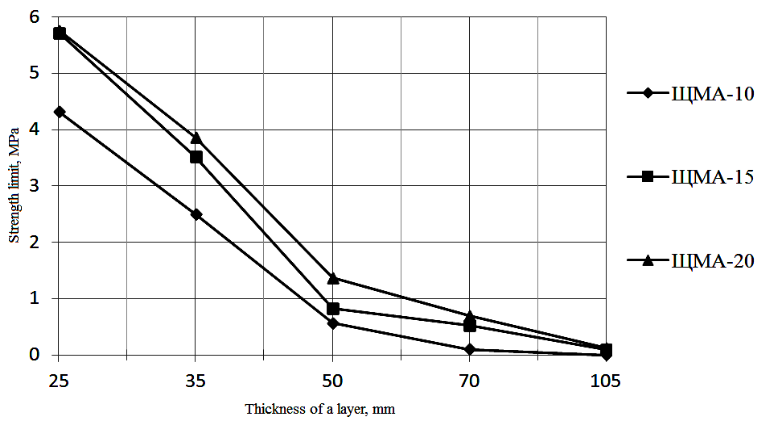


Fig. 3. Dependence of the compression strength (stone-asphalt concrete mix -10, stone-asphalt concrete mix -15, stone-asphalt concrete mix -20) on the relative thickness of a layer (temperature — 80 ºC)

The mathematical dependencies and approximation verifications obtained in the study of the strength limit are identified in Table 1.

Table 1

Mathematical dependencies of the compression strength limit
on the relative thickness of a layer

Type of a stone-asphalt concrete mix	Dependence	Approximation verification R^2
Stone-asphalt concrete mix -10	$y = 0.3514x^2 - 3.2146x + 7.278$	0.9913
Stone-asphalt concrete mix -15	$y = 0.3207x^2 - 3.3693x + 8.948$	0.9869
Stone-asphalt concrete mix -20	$y = 0.3207x^2 - 3.3693x + 8.948$	0.9869

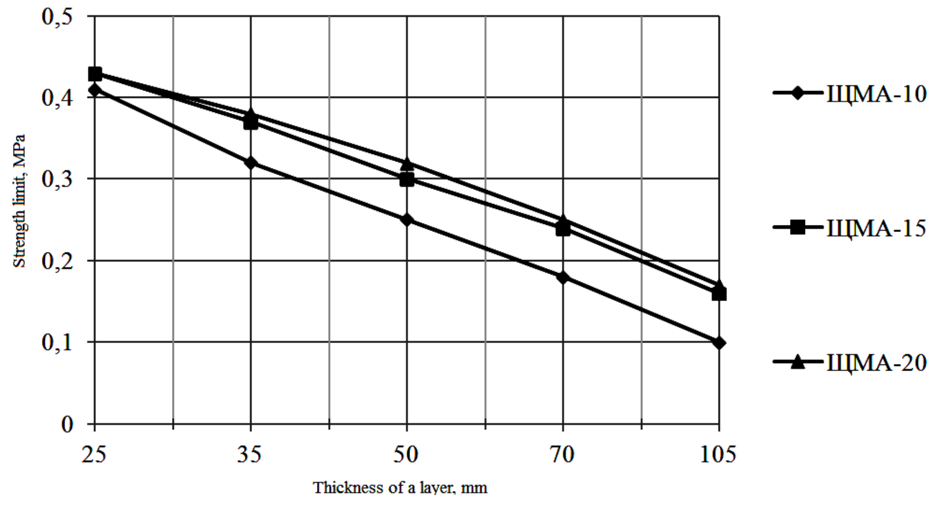


Fig. 4. Dependence of the shear strength limit
(stone-asphalt concrete mix -10, stone-asphalt concrete mix -15, stone-asphalt concrete mix -20)
on the releative thickness of the layer (temperature – 80 ºC)

The mathematical dependencies and approximation verifications obtained as a result of the study of the shear compression limit are in Table 2.

Table 2

Mathematical dependencies of the shear compression limit
on the relative thickness of the layer

Type of stone-asphalt concrete mix	Dependence	Approximation verification R^2
Stone-asphalt concrete mix -10	$y = 0.0014x^2 - 0.0846x + 0.49$	0.9984
Stone-asphalt concrete mix -15	$y = -0.0021x^2 - 0.0541x + 0.486$	0.999
Stone-asphalt concrete mix -20	$y = -0.005x^2 - 0.035x + 0.47$	1

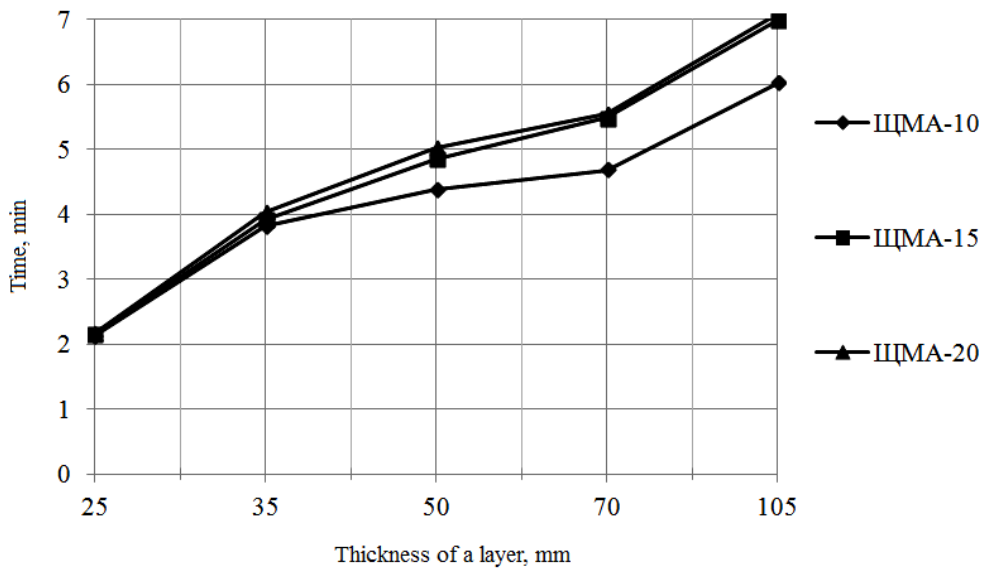


Fig. 5. Dependence of the strength increase
(stone-asphalt concrete mix -10, stone-asphalt concrete mix -15, stone-asphalt concrete mix -20)
on the relative thickness of the layer (temperature — 80 °C)

A strength limit of a standard kern is accepted as a unit (the diameter equals the height of the sample). The above data suggests that in choosing the parameters of compaction machines for laying thin layers of road surfaces, it is necessary to account for the thickness of the layer as it is responsible for providing the required compaction conditions.

3. Effect of the temperature on deformation and strength characteristics of stone-asphalt concrete mix

A strength limit of hot asphalt is known to depend on its temperature. The analysis of the guidelines on road surface cosntruction using hot asphalt mixes (GOST (ГОСТ) 9128-2009) and chip-mastics asphalt mixes (GOST (ГОСТ) 31015-2002) showed that there are differences in strength limits of hot asphalt concrete depending on its temperature. So, if at compression test temperature of 50 °C a strength limit for hot asphalt concrete is no less than 0.9…1.0 MPa, for stone-asphalt concrete mixes it is 0.6…0.7 MPa [4, 5].

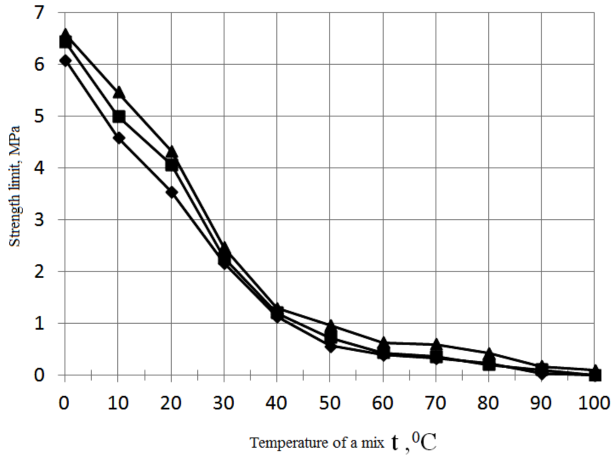
Compression strength limits at the test temperature of 20 °C are almost identical (2.0…2.5). Strength characteristics of hot stone-asphalt concrete mixes are largely dependent on its temperature. The above values of the guidelines conform to the operation temperatures of a road surface. Asphalt concrete has a high temperature in the distribution and compaction, which influences its strength characteristics.

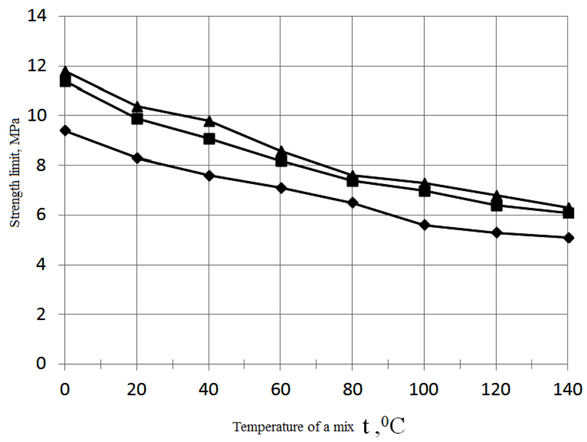
Considering the required condition, it is necessary that contact strains under the oeprating body of the compaction machine are close to the strnegth limit of the material being compacted. In order to make compaction really effective, it is necessary that a certain ratio of developing contact strains under the operating body of the compaction machine and strength characteristics of the material being compacted which is as follows

$$\sigma_\kappa = (0{,}9 - 1{,}0)[\sigma],$$

where σ_κ are contact strains under the drum of the roller, MPa; [σ] is the strength limit of the material being compacted, MPa [6].

The dependence of the compression strength limit on the temperature is in Fig. 6. The dependence of the compression strength limit on the temperature are in Fig. 7. The data from Fig. 6, 7 suggests that as the temperature of hot asphalt increases, its strength characteristics undergo a drastic change and are governed by the dependencies from Table 3. This should be taken into account in the construction of road surfaces using stone-asphalt concrete mixes.





ЩМА-10, ЩМА-15, ЩМА-20

Fig. 6. The dependence of the compression strength limit on the temperature

Fig. 7. The dependence of the shear strength limit on the temperature

Table 3

Mathematical dependencies of the compression and shear strength limit on the temperature

Type Stone-asphalt concrete mix	Compression strength limit		Shear strength limit	
	Mathematical dependencies	Approximati on verifications R^2	Mathematical dependencies	Approximation verifications R^2
Stone-asphalt concrete mix -10	$y = 0.0944x^2 - 1.7074x + 7.6373$	0.9887	$y = 0.0446x^2 - 1.0173x + 10.302$	0.9918
Stone-asphalt concrete mix -15	$y = 0.0995x^2 - 1.8127x + 8.1892$	0.9862	$y = 0.0744x^2 - 1.4042x + 12.609$	0.9967

End of Table 3

Type Stone-asphalt concrete mix	Compression strength limit		Shear strength limit	
	Mathematical dependencies	Approximation verifications R^2	Mathematical dependencies	Approximation verifications R^2
Stone-asphalt concrete mix -20	$y = 0.098x^2 - 1.8107x + 8.4533$	0.9811	$y = 0.069x^2 - 1.3952x + 13.093$	0.9929

Conclusions

1. A detail study was carried out into the temperature and strength characteristics of stone-asphalt concrete mix-10, stone-asphalt concrete mix-15, stone-asphalt concrete mix-20. The dependencies of compression and shear strength limits on the temperature and thickness of the layer of different types of stone-asphalt concrete mixes.

2. Based on the study, it was found that the strength characteristics of stone-asphalt concrete mix depends on the temperature of a mix and thickness of a layer of road surfaces, these dependencies should be taken into account in choosing an element of the compaction machine.

3. The temperature of the end of effective compaction of stone-asphalt concrete mix with БНД bitumen 60/90 is 115…110 °C and is identical for all types of stone-asphalt concrete mixes.

References

1. **Kiryuxin, G. N.** Stroitel'stvo dorozhnyx i ae'rodromnyx pokrytij iz shhebenochno-mastichnyx asfal'tobetonnyx smesej / G. N. Kiryuxin, E. A. Smirnov. — M., 2003. — 96 s.

2. **Metodicheskie rekomendacii** po ustrojstvu verxnix sloev dorozhnyx pokrytij iz

shhebenochno-mastichnogo asfal'tobetona (ShhMA) / FGUP «Soyuzdornii». — M.: FGUP «Soyuzdornii», 2002. — 36 s.

3. **Arutyunov, V. V.** Pervyj opyt stroitel'stva pokrytij iz shhebenochno-mastichnogo asfal'tobetona v Rossii / V. Artyuxov, G. Kiryuxin, V. Yumashev // Dorogi Rossii 21veka. — 2002. — № 3. — S. 58—61.

4. **GOST 9128-2009.** Smesi asfal'tobetonnye dorozhnye, ae'rodromnye i asfal'tobeton. Texnicheskie usloviya. — Vved. 2011–01–01. — M.: Standartinform, 2010. — 20 s.

5. **GOST 31015-2002.** Smesi asfal'tobetonnye i asfal'tobeton shhebenochno-mastichnye. Texnicheskie usloviya. — Vved. 2003–05–01. — M.: Izd-vo standartov, 2002. — 27 s.

6. **Zubkov, A. F.** Texnologiya ustrojstva dorozhnyx pokrytij s uchetom temperaturnyx rezhimov asfal'tobetonnyx smesej / A. F. Zubkov. — Tambov: Izd-vo Pershina R. V., 2006. — 152 s.

7. **Popov, A. P.** Problemy primeneniya sovremennyx texnologij dlya ustrojstva dorozhnyx pokrytij nezhestkogo tipa s povyshennymi e'kspluatacionnymi pokazatelyami v Tambovskoj oblasti / A. P. Popov, A. F. Zubkov // Vserossijskij nauchnyj kongress «Fundamental'naya nauka — resurs soxraneniya zdorov'ya zdorovyx lyudej»: sb. materialov, 4—5 dekabrya 2008 g. — Tambov, 2008. — S. 93—96.

8. **Zubkov, A. F.** Texnologiya stroitel'stva asfal'tobetonnyx pokrytij avtomobil'nyx dorog / A. F. Zubkov, V. G. Odnol'ko. — M.: Mashinostroenie, 2009. — 223 s.

9. **Zubkov, A. F.** Vybor texnologii i parametrov mexanizirovannogo zvena mashin dlya ustrojstva asfal'tobetonnyx dorozhnyx pokrytij / A. F. Zubkov // Dorogi Rossii 21 veka. — 2009. — № 4.

10. **Runenko, K. B.** Obosnovanie uplotnyayushhej nagruzki s uchetom trebovanij e'kspluatacionnyx parametrov asfal'tobetonnogo pokrytiya / K. B. Runenko, A. F. Zubkov // Problemy stroitel'stv, remonta i soderzhaniya avtomobil'nyx dorog yuga Rossijskoj Federacii i puti ix resheniya: sb. st. — Volgograd, 2009. — S. 21—25.

11. **Runenko, K. B.** Modelirovanie teplovyx processov pri ustrojstve dorozhnyx pokry-

tij s primeneniem shhebenochno-mastichnogo asfal'tobetona / K. B. Runenko, A. F. Zubkov // Vestnik central. regional. otdeleniya. — 2009. — Vyp. 8. — S. 301—307.

12. **Runenko, K. B.** Vliyanie uplotnyayushhej nagruzki na e'kspluatacionnye parametry asfal'tobetonnogo pokrytiya / K. B. Runenko, A. F. Zubkov // Trudy TGTU: sb. nauch. st. molodyx uchenyx i studentov / Tambov. gos. texn. un-t. — Tambov, 2009. — Vyp. 22. — S. 222—226.

13. **Kupriyanov, R. V.** Vliyanie texnologii rabot na e'kspluatacionnye pokazateli asfal'tobetonnogo pokrytiya / R. V. Kupriyanov, E. Yu. Evseev, A. F. Zubkov // Mexanizaciya stroitel'stva. — 2011. — № 1. — S. 25—26.

14. **Kupriyanov, R. V.** Primenenie shhebenochno-mastichnogo asfal'tobetona pri stroitel'stve avtomobil'nyx dorog Tambovskoj oblasti / R. V. Kupriyanov, A. F. Zubkov // Izvestiya Yugo-Zapad. gos. un-ta. — 2011. — № 5 (38), ch. 2. — S. 396—400.

15. **Kupriyanov, R. V.** Osobennosti texnologii ustrojstva dorozhnyx pokrytij s primeneniem shhebenochno-mastichnogo asfal'tobetona / R. V. Kupriyanov, A. F. Zubkov // Stroitel'stvo: materialy mezhdunar. nauch.-prakt. konf. — Rostov, 2012. — S. 153—155.