On the use of asphalt concrete mixes (according to the PNST)

M E Telegina¹, G A Averchenko¹, I R Mukharryamov², Y E Vasiliev³, E V Kotlyarskiy³

¹ Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
² Saint-Petersburg State University of Architecture and Civil Engineering, Vtoraya Krasnoarmeiskaya str. 4, 190005 St. Petersburg, Russia
³ Moscow Automobile and Road State Technical University (MADI), 64, Leningradsky Prosp., Moscow, 125319, Russia

E-mail: 79525087757@mail.ru

Abstract. The article is devoted to the preliminary national standard 184-2016 “Public roads. Asphalt concrete road mixes and asphalt concrete. Technical conditions”. The purpose of the work is to identify incorrect and unsubstantiated data of the preliminary national standard in comparison with the current interstate standard 9128-2009 “Asphalt concrete road, airfield and asphalt concrete mixtures. Technical conditions”. The following are ideas, some comments and suggestions that should be taken into account when developing and approving the preliminary national standard for asphalt concrete. The comparative analysis is aimed at identifying unsubstantiated technical characteristics, physical and mechanical parameters and criteria for testing asphalt concrete. The topics covered include “Grain compositions”, “Road classification”, “Voids”, “Dust”, “Sample preparation for testing”. The feasibility of using the new system was evaluated. The results are presented in the form of a comparative analysis of the requirements of current standards with the requirements of preliminary standards for the general characteristics of asphalt concrete mixtures. Proposals have been developed to adjust the physical and mechanical properties of asphalt concrete in accordance with the performance indicators of St. Petersburg roads.

1. Introduction

In 2017, a number of regulatory documents relating to asphalt concrete road mixes and asphalt concrete were put into effect, which became an alternative to GOST, called preliminary national standards (PNST). PNST were developed as part of the implementation of the “Superpave” system [1, 2].

The standard applies to asphalt concrete mixes and asphalt concrete intended for the construction of structural layers of public roads and airfields. PNST 184-2016 "Public roads. Asphalt concrete road mixes and asphalt concrete. Technical conditions".

The desire to improve the quality of asphalt concrete surfaces by implementing a new design system has led the Russian community of road industry specialists to great controversy [3]. The engineers at the lab say about the structural similarity of asphalt mixtures and their physical and mechanical properties. They do not see the need to replace complete technical documentation, laboratory equipment and design technology for asphalt concrete mix. Also, in their opinion, innovations are economically inefficient, and the timing of the introduction of a new design system in
all road construction organizations is uncertain [4, 5]. Other experts say that this design system can not be implemented "in parts", because it can lead to an uncertain result. In other words, the technical requirements of the new design system must be fully adapted to the operating conditions of Russian highways and take into account the climatic features of the terrain in which they pass. If possible, develop territorial requirements for asphalt concrete surfaces taking into account the amount of solar energy received at a given latitude, the maximum and minimum daily air temperatures [6, 7]. This will ensure that the requirements of the technical regulations of the Customs Union "Road safety" (TR CU 014/2011) are met.

Unfortunately, for a long period of consideration of the PNST, road workers were not able to come to a common opinion and start acting [8–11].

It is interesting to hear the statement of the honorary road worker M. A. Pokataev that in the 80's a similar project was adopted called "Plan for the introduction of new equipment and advanced technologies". In his opinion, the "introduction" of technologies is inefficient in all aspects, and new technologies should be stimulated by competition [12]. Many authors also consider production and technological aspects of implementing a new asphalt concrete design system [13–16].

The purpose of the work is to identify incorrect and unsubstantiated data of the preliminary national standard in comparison with the current interstate standard 9128-2009 "Asphalt concrete road, airfield and asphalt concrete mixtures. Technical conditions". The following are ideas, some comments and suggestions that should be taken into account when developing and approving the preliminary national standard for asphalt concrete.

The article is divided into sections on the following topics: "Grain compositions", "Road classification", "Voids", "Dust", "Sample preparation for testing". The feasibility of using a new asphalt concrete design system was assessed, taking into account the conditions of domestic operation of non-rigid roads. The results are presented in the form of a comparative analysis of the requirements of current standards with the requirements of preliminary standards for the general characteristics of asphalt concrete mixtures. Proposals have been developed to adjust the physical and mechanical properties of asphalt concrete in accordance with the performance indicators of St. Petersburg roads.

2. Materials and methods

2.1 PNST 184-2016. Grain composition
The traffic intensity of cargo vehicles is increasing every year, and the requirements for ABS strength in accordance with the PNST are decreasing. If in the USSR when selecting the composition of asphalt concrete mixtures of types A and B according to GOST 9128-2013 "Asphalt concrete road mixes, airfield and asphalt concrete. Technical conditions" a lot of research has been carried out, but today the changes in the new standard have no scientific justification for their application in Russia. We are talking about a mixture of A16OT, A16HE, A16OL, used in the device of the bases of road clothing under all traffic conditions, shown in table 1. Mixtures A16N, A16NN, A11NN, A11NL, which are used in the device of the lower layers of pavement, shown in table 2.
Table 1. Grain composition of mixtures for the road surface layer in accordance with table 1 PNS 184-2016

| Screen size, mm | A32OT | A22O | A16O | A32O | A22O | A16O | A32O | A22O | A16O |
|----------------|-------|------|------|------|------|------|------|------|------|
| 45.0           | 100   | -    | -    | 100  | -    | 100  | -    | 100  | -    |
| 31.5           | 90-100| 100  | -    | 90-100| 100  | -    | 90-100| 100  | -    |
| 22.4           | 75-90 | 90-100| 100  | 75-90 | 90-100| 100  | 75-90 | 90-100| 100  |
| 16.0           | -     | 75-90| 90-  | 75-90 | 90-100| -    | 75-90 | 90-100| 100  |
| 11.2           | -     | 75-90| -    | 75-90 | -    | -    | 75-90 | -    | 75-90 |
| 4.0            | 35-55 | 35-55| 35-55| 35-55| 35-55| 35-55| 50-70| 50-70| 50-70 |
| 2.0            | 25-40 | 25-40| 25-40| 25-40| 25-40| 25-40| 40-60| 40-60| 40-60 |
| 0.125          | 4-14  | 4-14 | 4-14 | 4-14 | 4-14 | 4-16 | 4-17 | 4-17 | 4-17 |
| 0.063          | 2-9   | 2-9  | 2-9  | 2-9  | 2-9  | 2-10 | 2-10 | 2-10 | 2-10 |

Table 2. Grain composition of mixtures for the road surface layer according to table 2 PNST 184-2016

| Screen size, mm | A32HT | A22H | A16H | A32H | A22H | A16H | A11H | A16H | A11H |
|----------------|-------|------|------|------|------|------|------|------|------|
| 45.0           | 100   | -    | -    | 100  | -    | -    | -    | -    | -    |
| 31.5           | 90-100| 100  | -    | 90-100| 100  | -    | -    | -    | -    |
| 22.4           | 75-90 | 90-100| 100  | 75-90 | 90-100| 100  | -    | 100  | -    |
| 16.0           | -     | 60-80| 90-  | 60-80 | 90-100| 100  | 90-100| 100  | 100  |
| 11.2           | -     | 65-80| -    | 60-80 | 90-100| 65-85| 90-100| -    | -    |
| 8.0            | -     | -    | 60-80| 60-80 | 90-100| 65-85| -    | 65-85| -    |
| 4.0            | 35-50 | 35-50| 35-50| 35-55| 35-55| 40-60| 40-60| 45-65| -    |
| 2.0            | 25-35 | 25-35| 25-35| 25-40| 25-40| 30-50| 30-45| 35-55| -    |
| 0.125          | 5-10  | 5-10 | 5-10 | 5-15 | 5-15 | 5-18 | 5-18 | 5-18 | 5-18 |

Based on data on the operation of Russian highways, it can be concluded that asphalt concrete mixtures containing small grain sizes are not able to meet the technical requirements for the lower layer of the road surface. Thus, it is proposed to exclude from the document asphalt concrete mixtures A16NT, A16NN, A11NN, A11NL, the feasibility of using which is not justified.

As a result, there are not so many asphalt concrete mixes that need to be leveled granulometric composition. Give the granules a certain, new border, using sieves with a cell size of 16 mm, 11.2 mm, 8 mm, 0.5 mm. It will be the guarantor of quality of asphalt concrete. Less capital-intensive changes in the part of granulometric compositions can be made in this PNST, using the standards for asphalt concrete PANK, developed in Finland. This is a document issued by the Advisory Commission on coatings (PANK GU), which presents the quality requirements used in Finland for asphalt concrete mixes and coatings, as well as raw materials for asphalt concrete. The book presents the principles of designing asphalt concrete mixes and coatings, as well as other related issues. The standards are intended for designers, contractors, developers, suppliers of raw materials, as well as for research institutions. It is worth noting that many of the researchers works are based on the analysis of data from experimental sites, which indicates the reliability of their published data [17–19].
2.2 PNST 184-2016. Classification of roads

One of the most significant parameters of road construction is the modulus of elasticity [15, 20–23]. Changes in load indicators directly affect the strength and durability of the road. The flaw in the PNST concerns the part of road classification by traffic conditions, where the calculated load is 10 tons per axle. Roads of high categories can now rely on a load of 11.5 tons per axle, which is not enough under real road operating conditions due to heavy vehicles weighing more than 26 tons. In the catalog of standard designs of non-rigid road clothes of the state company "AVTODOR", the load classes from transport are allocated, which directly depend on the number of load applications (from 3 million to 15 million or more) and the flow rate (from 20 km/h to 110 km/h) with reliability levels of 0.88-0.98, shown in table 3.

Table 3. Assignment of the transport load class according to STO "AVTODOR" 2.25-2016. "Catalog of typical designs of flexible pavement for roads"

| Total number of applications of the design load (115 kN), mln. | Speed limit | Slow** | Standard*** | High-speed**** |
|-------------------------------------------------------------|-------------|--------|-------------|---------------|
| < 3                                                          | Slow motion* | average | average      | average       |
| 3 – 7                                                        |             | high   | average      | high          |
| 7 – 15                                                       |             | ultra-high | ultra-high | ultra-high    |
| > 15                                                         |             | ultra-high | ultra-high | ultra-high    |

Note:
*average flow speed < 20 km/h
**average flow speed from 20 to 70 km/h
***average flow speed > 70 km/h
****average flow speed > 110 km/h

In the PNST at a load of 10 tons and the service time of road pavement, asphalt concrete mixtures are divided into three loading conditions:
- T (for heavy conditions, if more than 3 million applications load);
- N (for normal conditions, if the load applications are from 0.3 to 3 million);
- L (for light conditions when loads are applied less than 0.3 million times).

The method for reducing loads to the calculated uniaxial 10-ton load is shown in the Appendix A of PNST. The number of applications of uniaxial loads equivalent to 100 kN (10 tons) is calculated by the formula 1:

$$N_{100} = N_i \cdot K$$  \hspace{1cm} (1)

where:
- $N_{100}$ - the total estimated number of applications of a single-axis ten-ton load over the service life of the road surface;
- $N_i$ - conversion factor;
- $K$ - the total calculated number of applications of the calculated uniaxial load for the service life of the road surface for a given road, determined in accordance with current regulatory and technical documents in the field of design.

The conversion factor K is calculated using the formula 2:

$$K = (Q_i / 100) \cdot 4$$  \hspace{1cm} (2)

where:
- $Q_i$ - the calculated uniaxial load for a given highway, determined in accordance with the current normative and technical documents in the field of design, kN;
- 100 - Uniaxial load accepted in the classification according to the PNST data, kN;
4 - Conversion factor.
Comparing the accepted indicators, it becomes clear that the transport load in the PNST is much lower.

2.3 PNST 184-2016. Definitions of "Emptiness", «Dust»
In addition to the definitions of "residual porosity" and "porosity of the mineral part of asphalt concrete", the standard added the term "voids in the mineral aggregate" (PMZ). This is incorrect, since the asphalt concrete mix may contain moisture, air, vapors, etc. These substances differ in their aggregate state and density, which is very important.
Also, the purpose of introducing the following indicators is not clear: the ratio "dust-binder" (hereinafter - N/A) and "voids filled with bituminous binder" (hereinafter - PNB). The P/V ratio is actually higher than in accordance with the provisions of the PNST. The same is true for residual porosity. According to the PNST, the residual porosity data is lower than the calculated data.
According to PNST, dust is considered to be particles of mineral materials in a mixture of no more than 0.063 mm in size, although according to GOST 25100-2011 "Soils. Classification" dust has a size of less than 0.05 mm. The PNST suggests a conclusion about the effect of P/V on the binder, while if there are particles up to 0.063 mm in the asphalt concrete mixture, then these small particles have different mineralogical composition. It is very strange the ratio of N/A for PNST from 0.6 mm to 2.0 mm for all asphalt concrete mixes. This is incorrect. Let's look at the example in more detail. The data is presented in table 4.

Table 4. Example

| №  | Coating layer | Type of mix | Dust content, % | P/V | The boundaries of the contents of the binder, % |
|----|---------------|-------------|-----------------|-----|---------------------------------------------|
| 1  | Top           | A8B         | 6 – 12          | 0.6 | 10 – 20                                     |
| 2  | Top           | A8B         | 6 – 12          | 2.0 | 3 – 6                                       |

For example, if you arrange the top layer of the coating from a mixture of A8B or a mixture of AHB with a particle content of less than 0.063 mm in an amount of 6% to 12% and with a ratio of P/V equal to 0.6, the boundaries of the binder content will be 10% and 20%, respectively. If you arrange the top layer of the coating from A8B or AHB mixture with a particle content of less than 0.063 mm in an amount of 6% to 12% and with a ratio of P/V equal to 2, the boundaries of the binder content will be 3% and 6%, respectively.
Thus, 3% of the binder content is very small, and 20%, on the contrary, a lot. It is proposed to perform calculations and derive a new ratio of P/V for each type of asphalt concrete mixture, depending on the grain composition of the mixture. The analysis of hot compositions of asphalt concrete mixtures according to GOST 9128-2013 is presented in table 5.

Table 5. The analysis of hot compositions of asphalt concrete mixtures according to GOST 9128-2013

| №  | Coating layer | Type of mix          | P/V        |
|----|---------------|----------------------|------------|
| 1  | Top           | grained              | 1.45 – 1.55|
| 2  |               | coarse-grained dense | 1.83 – 2.11|
| 3  |               | fine-grained dense   | 1.82 – 2.14|
| 4  |               | sandy                | 2.10 – 2.29|
It can be seen that for denser mixtures, a larger amount of binder is needed to prevent leaching of the asphalt concrete pavement.

It should be noted that for the porous asphalt concrete (> 5%) proposed value filling the pores in the mineral mixture of asphalt cement are too high, and for a dense asphalt underestimated. All this makes it impossible to provide the required values of residual porosity in the asphalt concrete mix.

2.4 PNST 184-2016. Sample preparation and testing

The PNST offers the preparation and testing of samples according to the Marshall method. It should be noted that GOST 12801-67 "Mixes of asphalt concrete (hot and warm) road and airfield and asphalt concrete. Test methods", GOST 12801-71 "Mixtures of asphalt concrete road, airfield and asphalt concrete. Test methods" and GOST 12801-77 "Mixtures of asphalt concrete road, airfield and asphalt concrete. Test methods" this method is present. But in 1967-1977, this method was never implemented. Gorelyshev N. V. found that when compacting samples by ramming using the Marshall method, the crushed stone is approximately the same as when compacting samples in the laboratory (vibration compaction and compression). "The structure of asphalt concrete in a rammed sample differs from its structure in the coating, which leads to non-identical properties of the material in the sample and in the coating". The work is described in his doctoral dissertation "Research of asphalt concrete frame structure and its performance properties in road clothing" in 1978.

In addition to the above, foreign colleagues (in 1981-1982) from the University of Notingham conducted comparative studies of various compositions of bituminous materials under various test schemes: triaxial compression under cyclic load; static tests under triaxial compression; static tests under uniaxial load; tests on the Marshall test. As a result, it was found that tests for three-axis compression under cylindrical loads best reflect the actual working conditions of asphalt concrete surfaces (Fig. 1).

Static tests of samples for uniaxial compression and Marshall tests have a linear relationship between them, but the accuracy and convergence of the Marshall test is significantly inferior to tests for uniaxial compression. Thus, to obtain reliable results for Marshall, at least eight parallel samples should be tested, and three are sufficient for uniaxial compression [24, 25].

There are no innovations in the Marshall test and it is completely unjustified to switch to manufacturing samples using this method to determine the following indicators: volume density, water saturation, water resistance and the Marshall test. The number of compacting blows (50) is also unclear, while the established number is 75.

In addition, it is proposed to set the value of residual porosity for asphalt concrete used for the device of the bases and the lower layer of the coating to no more than 5%. This will improve the resistance of the layers to tensile forces, reduce cracking from below, and help avoid reflected cracks in the upper layer of the road surface.

Not justified an understatement of the brand of crushed stone for strength and lasagnette.

It is important to include in the main test indicators not only the average value of the track depth, but also the angle of inclination of the track formation curve. This is obtained immediately from the experiment. About the requirements for binders-include the current GOST 22245-90 "Road oil Bitumen viscous. Technical conditions".
2.5 PNST 184-2016. Wear resistance in the cold season

It should be noted that in recent years, due to a sharp increase in the number of cars and the speed of their movement, one of the main indicators of the stability of coatings is their wear resistance in the cold period of the year. According to the service for the operation of the Ring road (KAD) of Saint Petersburg, the traffic intensity on high-speed lanes reaches more than 3 thousand cars per hour, and the daily rate is about 35-40 thousand cars. With an average flow speed of up to 124 km/h, and individual cars up to 220 km/h.

In this regard, it is proposed in PNST to introduce additional testing of aggregates for the top layer coating method according to the Scandinavian "Nordic-test" (EN 1097-9), as the wear resistance of the asphalt top coat on motorways and Express roads in the cold season of the actions of studded tires, especially when channeled high-speed movement becomes the main criterion of sustainability.

Approximately 300 samples of crushed stone from various rocks of different deposits were tested in the laboratory of "NCC roads". As a result, it turned out that the most wear-resistant material is crushed stone from porphyry, the next was gabbro-diabase. Wear resistance of asphalt concrete is caused by the abrasion of crushed stone, its quantity, the correctness of the selected grain composition and the binder used. According to experts on the content of the road, for one year of service, the depth of the track wear of the coating on average is about 10 mm in areas with the use of crushed mastic asphalt on gabbro - diabase and about 8 mm - when using porphyrite rubble.

---

Fig. 1. Assembly form for compaction of samples
3. Results and Discussion
Summarizing the results of the work, we highlight the following proposals that should be taken into account when developing and approving the PNST 184-2016 "Public roads. Asphalt concrete road mixes and asphalt concrete. Technical conditions":

1. Exclude asphalt-concrete mixes of types A16OT, A16ON, A16OL used at the device of the bases of road clothes, and A16NT, A16NN, A11NN, A11NL used at the device of the lower layers of the covering of road clothes;
2. Consider the standards for PANK asphalt concrete developed in Finland for making less capital-intensive changes in the part of granulometric compositions;
3. Consider the correct use of a transport load of 10 tons per axle instead of 11.5 tons per axle, i.e. reducing it;
4. Explain the feasibility of changing the size of dust particles from 0.05 mm to 0.063 mm;
5. Perform calculations and output a new ratio of P/V for each type of asphalt concrete mix, depending on the grain composition of the mix;
6. Note that for porous asphalt concrete (>5%), the proposed values for filling the pores in the mineral part of the mixture with bituminous binder are overstated, and for dense asphalt concrete, on the contrary, they are underestimated;
7. Set the value of the residual porosity for asphalt concrete used for the device of the bases and the lower layer of the coating, set no more than 5%;
8. Justify understating the brand of crushed stone in terms of strength and breaminess;
9. Justify the need to prepare and test samples using the Marshall method without choosing an alternative method for testing samples;
10. Add to the main test indicators not only the average value of the track depth, but also the angle of inclination of the track formation curve;
11. Introduce tests of crushed stone for the top layer of the coating according to the Scandinavian method "Nordic-test" (EN 1097-9).

4. Conclusions
1. In connection with the increase in the intensity of motor traffic demands on the quality of asphalt concrete pavements has increased significantly. Traffic safety directly depends on the quality of the road surface. Ensuring traffic safety is a key goal in the construction and operation of highways.
2. The Introduction of preliminary national standards has a huge impact on the economic, technological, production components and qualifications of road workers. Striving for high quality roads through the introduction of a new asphalt concrete design system, there is a sharp need for monetary resources, which makes it difficult for almost all road construction organizations due to their interdependence.
3. The Feasibility of using a new system for designing asphalt concrete taking into account the conditions of domestic operation of roads with non-rigid pavement is not justified today. Perhaps a more effective action would be to modernize the technical equipment of road construction services, improve the existing standards for designing asphalt concrete, and systematically introduce innovations.

References
[1] Musselman J A, Choubane B, Page G C, Upshaw P B 1998 Superpave Field Implementation: Florida’s Early Experience. Transp. Res. Rec. J. Transp. Res. Board. 1609 51–60
[2] Kakrasul J Superpave: How it Works and How it Can Work for Local Agencies
[3] Kiryuhin G N, Dzhumanov R B 2014 Advantages and disadvantages of design asphalt «Superpave»
[4] Easa S M 2020 Superpave Design Aggregate Structure Considering Uncertainty: I. Selection of Trial Blends. J. Test. Eval. 48 20170682
[5] Averchenko G A, Kvitko A V, Barashev M N 2017 Ortotropnaya kompozitnaya plita [Orthotropic composite plate deck bridge]. Utility Model Patent № RU 174705 U1E01D 19/12 (2006.01) 31

[6] Averchenko G A, Kvitko A V 2017 Ortotropnaya kompozitnaya plita [Orthotropic composite plate deck bridge]. Utility Model Patent № RU 173490 U1, E01D 19/12 (2006.01), E01D 101/40 (2006.01) 25

[7] Radovskii B S 2007 Designing the composition of asphalt mixtures in the USA using the Superpave method Dorozhnaya tekhnika Road Mach 86–99

[8] Han D, Wei L, Zhang J 2016 Experimental Study on Performance of Asphalt Mixture Designed by Different Method Procedia Engineering 275 407–414

[9] Zhang Z Q, Tao J, Yang B, Li N L 2009 Methodology of mixing and compaction temperatures for modified asphalt mixture Geotechnical Special Publication 5 34–41

[10] Fernandes F M, Pais, J C 2017 Laboratory observation of cracks in road pavements with GPR. Constr. Build. Mater 154 1130–1138

[11] Hosseini F, Hossain S M K, Fu L, Johnson M, Fei Y 2015 Prediction of Pavement Surface Temperature Using Meteorological Data for Optimal Winter Operations in Parking Lots Proceedings of the International Conference on Cold Regions Engineering 39 440–451

[12] Zhang H, Yu T, Huang Y 2020 Comparative analysis of HMA aggregate variability based on impacting and gyratory compaction. Constr. Build. Mater 242

[13] Khasawneh M A, Alsheyab M A 2020 Effect of nominal maximum aggregate size and aggregate gradation on the surface frictional properties of hot mix asphalt mixtures. Constr. Build. Mater 244

[14] Ramadan K Z, Al-Khateeb G G, Taamneh M M 2019 Mechanical properties of styrofoam-modified asphalt binders Int. J. Pavement Res. Technol

[15] Priyanka B A, Sarang G, Ravi Shankar A U 2019 Evaluation of Superpave mixtures for perpetual asphalt pavements Road Mater. Pavement 1952–1965

[16] Pereira P, Pais J 2017 Main flexible pavement and mix design methods in Europe and challenges for the development of a European method J. Traffic Transp. Eng. 4 316–346

[17] Makowska M, Pellinen T 2016 Development of specifications and guidelines for hot in-place recycling in finland—outline and framework RILEM Bookseries 68 851–862

[18] Makowska M, Aromaa K, Pellinen T 2017 The rheological transformation of bitumen during the recycling of repetitively aged asphalt pavement Road Mater. Pavement Des. 18 50–65

[19] Changsha H S 2009 Road pavement material characterization and rehabilitation: selected papers from the GeoHunan International Conference

[20] Mohammad L N, Obulareddy S, Cooper S, Bae A 2008 Permanent deformation analysis of HMA mixtures using simple performance tests. In: Efficient Transportation and Pavement Systems: Characterization, Mechanisms, Simulation, and Modeling - Proceedings of the 4th International Gulf Conference on Roads 601–610

[21] Vallejo L E, Chik Z 2009 Fractal and laboratory analyses of the crushing and abrasion of granular materials. Geomech. Eng. 1 323–335

[22] Gao J, Wang H, Bu Y, You Z, Zhang X, Irfan M 2020 Influence of Coarse-Aggregate Angularity on Asphalt Mixture Macroperformance: Skid Resistance, High-Temperature, and Compaction Performance. J. Mater. Civ. Eng. 32

[23] Association of Asphalt Paving Technologists Technical Sessions 1985 Marshall Procedures for Design and Quality Control of Asphalt Mixtures. Asphalt Paving Technology Proceedings 54 265-284

[24] Ma L J, Zhang J Y, Li Z 2013 The road-test of high performance asphalt mixture with Superpave Applied Mechanics and Materials 1576–1579