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PAVEMENT TEMPERATURE AND THE RESULTS OF TESTS CONDUCTED USING CONVENTIONAL METHODS

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Abstract. To perform all experimental procedures and computational analyses in accordance with the adopted methodology, the climatic conditions of the Republic of Kazakhstan were considered as a representative case study. Initially, the design air temperature was determined with a specified level of statistical reliability. For this purpose, meteorological data obtained from stations located in proximity to the study area were processed and incorporated into the calculations.

According to the Superpave methodology, pavement temperature determination is based on the analysis of climatic variations over a 20-year period. The analysis showed that the average shaded air temperature during seven consecutive hottest days in a given year is 38.7 °C. It was established that, for any particular year, there is a 50% probability that the air temperature will be either higher or lower than this value. Therefore, adopting a summer design temperature of 38.7 °C alone is inappropriate, since, for example, over a 14-year period, approximately seven years may experience higher temperatures. Consequently, assuming a normal probability distribution for this parameter would lead to inaccurate results.

The calculations were carried out using climatic data from the last 20 years, reflecting recent climate variability affecting asphalt concrete pavements in Kazakhstan. Within the Superpave framework, test methods for evaluating the rheological behavior and low-temperature resistance of bituminous binders were described, taking into account both short-term and long-term oxidative aging. These properties were assessed using the bending beam rheometer (BBR) method. In addition, the testing requirements and specific characteristics of mineral fillers were considered, and the methodology for determining the asphalt concrete mixture composition, including the calculation of the optimum bitumen content, was examined.

Key words: bitumen, super pave, rheological properties, road construction.

Introduction

Asphalt concrete pavements are a critical component of modern transportation infrastructure, providing a smooth and durable surface for vehicle movement. However, exposure to traffic loading, environmental conditions, and oxidative aging can lead to various forms of damage, including cracking and surface degradation of pavements [1]. In response to these challenges, researchers and practitioners worldwide have developed and implemented a range of strategies and technologies aimed at improving the performance and durability of asphalt concrete pavements.

Asphalt (bitumen), as a viscoelastic material, plays a crucial role in the overall durability and damage resistance of asphalt concrete mixtures. Its rheological properties must be thoroughly characterized prior to pavement service. Typically, specific grading systems are used to evaluate and select appropriate asphalt binders. The Superpave performance grading (PG) system was the first to establish a direct relationship between the physical properties of asphalt binders and their in-service performance by explicitly accounting for pavement conditions. Conceptually, this approach represents a significant advancement compared with traditional penetration and viscosity grading systems. To meet performance requirements, the Superpave PG system introduced new test methods and specifications [2-5].

At present, three primary binder evaluation systems are used worldwide: the penetration grading system, the viscosity grading system, and the Superpave performance grading (PG) system [6,7]. The penetration and viscosity grading systems rely on penetration and viscosity tests, respectively, as their principal characterization methods. The penetration test is empirical in nature and is conducted at a constant temperature of 25 °C. The non-Newtonian behavior of asphalt binders at this temperature, coupled with variations in shear rate during testing, can influence penetration test results [8,9]. Unlike penetration depth, viscosity is not an empirical parameter but a fundamental engineering property. Nevertheless, binders originating from the same source may exhibit significantly different behaviors after placement in the pavement due to viscosity changes caused by short-term oxidative aging.

It has been identified that both the penetration and viscosity grading systems share three major limitations, which can be summarized as follows [10]:

1. Both systems rely heavily on empirical tests, and no direct relationship is established between the measured physical properties at test temperatures and the actual in-service pavement performance. Interpretation of test results therefore requires substantial empirical experience.
2. Neither the penetration nor the viscosity grading system accounts for long-term oxidative aging. Laboratory simulation of long-term aging is essential for evaluating fatigue cracking and thermal cracking of asphalt concrete pavements after extended service life.
3. Pavement conditions – including temperature, traffic speed, traffic volume, and pavement structure – are not fully considered, despite their significant influence on pavement performance.

Superpave technology has been widely adopted in many countries, where it has been accepted as a standard pavement design system due to its proven advantages and improved performance compared with earlier design approaches [11]. The successful implementation of Superpave technology in pavement design and construction practices has resulted in enhanced durability, increased resistance to rutting and cracking, and overall improvement in pavement performance [12].

It is important to note that the extent of Superpave implementation varies among countries depending on local conditions, infrastructure needs, and available resources. Nevertheless, growing interest and consistently positive research outcomes indicate that Superpave is increasingly recognized worldwide as a valuable technology for the design and construction of high-performance pavements [13-15].

Materials and research methods

Two primary mechanisms are involved in the oxidation of bitumen: evaporation of light oily fractions and oxidation resulting from reactions with atmospheric oxygen. Bitumen binder undergoes oxidation during mixing at the plant and during pavement construction through both mechanisms, due to the combined effects of high temperature and air flow. To model this oxidation process, the Superpave specifications employ the Rolling Thin Film Oven Test (RTFOT).

After completion of asphalt concrete pavement construction, the oxidation process continues; however, it occurs under ambient service temperatures rather than the elevated temperatures experienced during production and placement. According to the Superpave specifications, in-service aging is simulated using the Pressure Aging Vessel (PAV), which is applied after RTFOT. Thus, following these procedures, the binder can be evaluated in a state representing oxidation during production, construction, and long-term service conditions.

Rolling Thin Film Oven Test (RTFOT) (AASHTO T240 or ASTM D2872)

The RTFOT method serves two primary purposes. First, it is used to determine the physical properties of oxidized bitumen binders relevant to subsequent performance. Second, it allows quantification of the mass loss of volatile components released from the binder during testing. Mass loss due to volatilization is an indicator of binder oxidation occurring during mixing and construction. In some cases, an apparent increase in binder mass may be observed during RTFOT due to oxygen uptake during oxidation. Throughout the RTFOT procedure, the bitumen films are

continuously exposed to elevated temperatures and a controlled air flow. In certain cases, the rolling action may promote dispersion of modifiers (e.g., some polymers) within the binder.

An electronically controlled convection oven is required to conduct the RTFOT. The oven is equipped with a vertically rotating carousel capable of holding flasks containing the material. An air jet directs air onto each flask when it reaches the lowest position on the rotating platform. Prior to testing, the oven must be preheated and maintained at 163 °C for up to 16 hours. After the flasks containing the bitumen are placed inside and the oven door is closed, the thermostat must be capable of restoring the set temperature within 10 minutes.

For preparation of binders for RTFOT aging, the binder should be heated to a fluid state without exceeding 150 °C. Each RTFOT flask is then filled with 35 g of binder (± 0.5 g), as illustrated in Figure 3.6. According to Superpave requirements, eight flasks are used per test. Two flasks are designated for determining mass loss, while the remaining six are reserved for subsequent testing. The two flasks used for mass loss determination must be weighed with an accuracy of 0.001 g prior to testing.

Once the flasks containing the binder are placed on the rotating carousel, the platform is set to rotate at 15 revolutions per minute. The air flow rate is regulated at 4000 mL/min, and the samples are maintained under these conditions for 85 minutes.

After aging, the two flasks designated for mass loss measurement are cooled to room temperature and reweighed with an accuracy of 0.001 g; these samples are then discarded. The remaining samples are poured into a single container and thoroughly mixed until a homogeneous binder is obtained. According to AASHTO T240, the aged binder should be gently poured into another container without scraping; however, this practice remains a subject of discussion in research. Scraping may be required for binders modified with certain additives to obtain a representative and sufficient sample volume. The RTFOT-aged binder is subsequently used for Dynamic Shear Rheometer (DSR) testing, while the remaining material is either transferred into PAV containers for long-term aging or stored in equal portions in smaller containers for further testing.

Results and Discussion

All experimental procedures and computational analyses were conducted in accordance with the adopted methodology, using the climatic conditions of the Republic of Kazakhstan as a representative case study. The design air temperature was first established with a defined level of statistical confidence. For this purpose, meteorological data obtained from stations located near the study area were processed and incorporated into the calculations.

Within the Superpave framework, pavement temperature estimation is based on an analysis of climatic variations over a 20-year period. The results indicate that the mean shaded air temperature during seven consecutive hottest days of a given year is 38.7 °C. It was determined that, in any given year, there is a 50% probability that the air temperature will exceed or fall below this value. Therefore, adopting 38.7 °C as the summer design temperature alone is not statistically justified, as approximately half of the years within a 14-year interval may experience higher temperatures. Consequently, assuming a normal probability distribution for this parameter may lead to inaccuracies.

Analysis of the 20-year dataset showed that the standard deviation of air temperature during the hottest week of the year is 1.71 °C. Based on probability integral tables, a confidence level of 0.9772 corresponds to two standard deviations, which is approximately 98%. Accordingly, the summer air temperature estimated at a 98% confidence level is calculated as $(38.7\text{ °C} + 2 \times 1.71\text{ °C}) = 42.14\text{ °C}$. This value suggests that such extreme summer conditions are likely to occur approximately once every 50 years.

The calculations were performed using climatic data from the past 20 years, reflecting recent climate variability affecting asphalt concrete pavements in Kazakhstan. In accordance with the Superpave methodology, the rheological behavior and low-temperature performance of bituminous binders were evaluated considering both short-term and long-term oxidative aging. These properties were assessed using the bending beam rheometer (BBR) test. Furthermore, the testing requirements

and specific characteristics of mineral fillers were considered, and the procedure for determining the asphalt concrete mixture composition, including the calculation of the optimum bitumen content, was addressed.

The calculations were performed based on climatic data from the past 20 years reflecting climate change effects on asphalt concrete pavements in Kazakhstan. Within the Superpave framework, test methods for evaluating the rheological shift and low-temperature resistance of bituminous binders – considering both short-term and long-term oxidative aging – were described using the bending beam rheometer (BBR) method. In addition, the testing requirements and specific characteristics of mineral fillers were taken into account, and the procedure for determining the complete asphalt concrete mixture composition and calculating the optimum bitumen content was addressed.

Similarly, using observational data from the same meteorological station, the minimum daily winter air temperature was processed. In this case, a standard deviation of 3.25 °C was applied to represent a 98% confidence level. Accordingly, the low air temperature was calculated as $(-16.4\text{ °C} - 2 \times 3.25\text{ °C}) = -22.9\text{ °C}$.

Based on these air temperatures, the predicted pavement surface temperature can be determined. The calculated summer pavement temperature at a depth of 20 mm below the surface is expressed by Equation (1):

$$T_{20mm} = 0.9545(T_{air} - 0.00618Lat^2 + 0.2289Lat + 42.2) - 17.78 \quad (1)$$

where T_{air} is the shaded air temperature (°C), °C; Lat is the latitude in degrees north. In deriving this equation, a solar radiation absorption coefficient of 0.9, solar transmissivity of 0.81, atmospheric radiation of 0.7, and a wind speed of 4.5 m/s were assumed.

For the Mangystau Region, the latitude was determined as 42.18°. Using the calculated summer air temperature of 42.14 °C, the predicted summer pavement temperature was obtained as $T_{20mm} = 61.44\text{ °C}$.

According to Canadian researchers, adopting winter pavement temperature equal to air temperature leads to excessive conservatism; therefore, the following relationship was proposed (Equation 2):

$$T_{min} = 0.856T_{air} + 1.7 \quad (2)$$

Using the minimum one-day air temperature of -22.9 °C, the predicted winter pavement temperature was calculated as $T_{min} = -17.9\text{ °C}$.

Binder grades are assigned in 6 °C increments. Accordingly, for the calculated summer pavement temperature of 61.44 °C, the nearest higher-grade PG 64 was selected, while for the low-temperature condition, PG -22 was chosen. Thus, for the climatic conditions of the Mangystau Region, the PG 64-22 binder grade is considered the most appropriate. In both cases, the reliability exceeds 99%, as rounding to a 6 °C increment provides an additional safety margin. Nevertheless, the predicted air temperatures should be periodically reassessed by adjusting the confidence level, and the reliability of the selected binder grade should be discussed after determining the design pavement temperatures.

In general, when the absolute difference between the design high and low pavement temperatures exceeds 90 °C, the use of polymer-modified bitumen is recommended instead of conventional bitumen. Therefore, pavement temperatures must be calculated separately for each region while accounting for local climatic conditions, as studies indicate that temperatures have changed significantly over the past 10–20 years. Indeed, widespread reports confirm a clear warming trend and its substantial impact.

In the PG 64-22 example, the temperature difference is $(64 - (-22)) = 86\text{ °C}$, indicating that polymer modification is not required. However, for a PG 58-34 grade, the difference would be $(58 - (-34)) = 92\text{ °C}$, implying that binder modification is necessary. According to Figure 4 from the

recommendations of the Kazakhstan Road Research Institute, approximately 80% of the country's territory requires binder modification, i.e., where the temperature difference exceeds 90 °C. However, the design grades presented in this document were calculated using outdated climatic data. Considering recent global climate changes, recalculation using updated datasets is strongly recommended. As a result, regional modification requirements and polymer content percentages may change. For example, for the Mangystau Region, calculations based on recent climate data yield a PG 64-22 grade, whereas calculations using data from the past 40 years indicate a PG 64-28 grade, demonstrating a notable discrepancy.

The minimum and maximum pavement temperatures are observed to be -46 °C and 82 °C, respectively. In fact, in the northern United States, pavement temperatures do not fall below -46 °C, while average 7-day summer pavement temperatures may reach up to 82 °C in some regions; however, in most areas, they typically do not exceed 70 °C.

The PG 64-22 binder grade indicates suitability for pavements with a design high temperature of 64 °C and a design low temperature of -22 °C under moderate to high traffic speeds (greater than 70 km/h), accommodating approximately 10 million equivalent single axle loads (ESALs) of 80 kN over the binder's service life. However, for slow-moving traffic conditions with average speeds between 20 and 70 km/h (e.g., airport taxiways or intersections), or for pavements subjected to more than 10 million ESALs per lane, it is recommended to select a binder one grade (6 °C) higher on the high-temperature side. In the present example, this would require the use of PG 70-22 for the Mangystau Region. If both conditions apply simultaneously, the selection of a two-grade-higher 'hot' binder, such as PG 76-22, is recommended.

The true PG grade of the bitumen will be defined in the following sections. Subsequently, to investigate the effects of various polymers on the base bitumen, the true PG grade of each binder used in this study will be determined, and the results of conventional tests and rheological characteristics will be compared with the requirements for polymer-modified bitumen (PMB). Determining the true grade of modified PG bitumen prior to quality assessment in accordance with the national standard RK ST 2534 is critically important. Based on test results obtained using conventional methods, both before and after short-term aging, the properties of modified binders in accordance with RK ST 2534 are presented in Tables 1 and 2 for PMB.

Table 1 – Results of mixtures prepared with low-viscosity bitumen

Tests	B1	B+BNS	B+SBS	B+Titan
Penetration (25°C, 100 g, 5 s) 0.1 mm	83.2 (70-100)	70.2 (51-70)	55.1 (51-70)	53.4 (35-50)
Softening Point, °C	49.0 (≥47)	57.0 (≥62)	62.2 (≥62)	79.2 (≥65)
Flash Point, °C	250 (≥230)	280 (≥235)	285 (≥235)	285 (≥240)
Density (25 °C), g/cm ³	1.015 (1.0-1.1)	1.028 (1.0-1.1)	1.031 (1.0-1.1)	1.026 (1.0-1.1)
Recovery (25 °C), %	-	81.2 (≥60)	82.6 (≥60)	- (≥60)
<i>Storage stability:</i>				
Softening point differences, °C	-	1.4 (≤5)	1.5 (≤5)	1.2 (≤5)
Penetration difference, 0.1 mm	-	1	1	1
Dynamic shear rheometer (DSR) (G*/sinδ≥1 kPa) Limit temperature, (°C)	66.5 (≥64)	77	77.1	80
<i>Short-term oxidation (RTFOT):</i>				
Weight change, %	0.601 ≤0.6	≤0.5 0.204	≤0.5 0.197	≤0.5 0.156
<i>Softening point change:</i>				
Increase, °C	5.5 (≤6)	5.5 (≤6)	5.5 (≤6)	5.0 (≤6)
Shrinkage, °C	- (≤5)	- (≤5)	- (≤5)	- (≤5)
Bending beam rheometer (BBR) Hardness (s≤300MPa, m≥0.300) Limit temperature, (°C)	28	22	22	22
After short-term oxidation (DSR)	67	77.4	77.5	81

(G*/sinδ≥2.2 kPa) Limit temperature, (°C)	(≥64)			
After RTFOT+PAV (DSR) (G*/sinδ≤5000 kPa) Limit temperature, (°C)	27 (≤31)	26.2 (≤31)	26.1 (≤31)	26.6 (≤31)
Note – () Requirements for the adhesive according to the standard				

Table 2 – Mixture results with low viscosity bitumen

Сынақтар / Тұтқыр түрлері	B2	B+BNS	B+SBS	B+Titan
Penetration (25°C, 100 g, 5 s) 0.1 mm	122.3 (100-130)	68.9 (51-70)	63.5 (51-70)	67.8 (35-50)
Softening Point, °C	47.4 (≥47)	57.0 (≥62)	66.6 (≥62)	74.2 (≥65)
Flash Point, °C	270 (≥230)	280 (≥235)	285 (≥235)	285 (≥240)
Density (25 °C), g/cm ³	1.011 (1.0-1.1)	1.020 (1.0-1.1)	1.021 (1.0-1.1)	1.016 (1.0-1.1)
Recovery (25 °C), %	-	81.2 (≥60)	82.6 (≥60)	- (≥60)
<i>Storage stability:</i>				
Softening point differences, °C	-	1.7 (≤5)	1.7 (≤5)	1.6 (≤5)
Penetration difference, 0.1 mm	-	1	1	1
Dynamic shear rheometer (DSR) (G*/sinδ≥1 kPa) Limit temperature, (°C)	60.1 (≥64)	75	76.2	77
<i>Short-term oxidation (RTFOT):</i>				
Weight change, %	0.603 ≤0.6	≤0.5 0.210	≤0.5 0.205	≤0.5 0.213
<i>Softening point change:</i>				
Increase, °C	5.5 (≤6)	5.5 (≤6)	5.5 (≤6)	5.0 (≤6)
Shrinkage, °C	- (≤5)	- (≤5)	- (≤5)	- (≤5)
Bending beam rheometer (BBR) Hardness (s≤300MPa, m≥0.300) Limit temperature, (°C)	28	22	22	22
After short-term oxidation (DSR) (G*/sinδ≥2.2 kPa) Limit temperature, (°C)	62.4 (≥64)	76.1	77.5	78.3
After RTFOT+PAV (DSR) (G*/sinδ≤5000 kPa) Limit temperature, (°C)	27.9 (≤31)	25.4 (≤31)	26.1 (≤31)	26.4 (≤31)
Note – () Requirements for the adhesive according to the standard				

For sections where the average traffic speed does not exceed 20 km/h or where traffic movement is very slow, a binder grade two levels higher on the high-temperature side is selected, i.e., PG 76-22. Accordingly, in regions where the actual design summer pavement temperature reaches 70 °C, it may be necessary to increase the high-temperature grade by up to 12 °C, as indicated in the table, resulting in the selection of a PG 82 binder.

Conclusion

As a result of climatic changes observed over the last 20 years prior to 2020 in the Mangystau Region, the pavement temperature at a depth of 20 mm was determined to correspond to a PG 64-22 grade, which differs from the temperature values recommended in R RK 218-96-2013. Considering population growth and the development of transportation systems in the region, it is evident that the bituminous binders currently recommended must be mandatorily modified to enhance their performance and durability. Among the three polymers evaluated, Titan 3686 demonstrated superior resistance and was identified as a practical modifier due to its favorable viscosity characteristics during pavement construction. In contrast, Butonal NS and SBS required

significantly higher mixing and compaction temperatures, necessitating specialized equipment with elevated heating capacities for pavement construction operations.

To accurately characterize the properties of bituminous binders and their polymer-modified counterparts, the Superpave technology was investigated and recognized as an effective and reliable approach. Furthermore, a comparison between the conventional asphalt concrete mixture design method currently in use and the Superpave methodology revealed that the traditional approach does not adequately address several critical performance-related factors. In particular, the Superpave-based design demonstrated a 16.7% reduction in rut depth, which contributes to extending the interval between maintenance activities and increases the service life of the pavement by approximately 20–30%.

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ЖОЛ ЖАБЫНДЫСЫНЫҢ ТЕМПЕРАТУРАСЫ ЖӘНЕ ДӘСТҮРЛІ ӘДІСТЕРМЕН ЖҮРГІЗІЛГЕН СЫНАҚ НӘТИЖЕЛЕРІ

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Аңдатпа. Барлық эксперименттік рәсімдер мен есептік талдаулар қабылданған әдістемеге сәйкес орындалуы үшін Қазақстан Республикасының климаттық жағдайлары үлгілік жағдай ретінде қарастырылды. Алдымен белгілі бір статистикалық сенімділік деңгейінде есептік ауа температурасы анықталды. Бұл мақсатта зерттеу аймағына жақын орналасқан метеорологиялық станциялардан алынған деректер өңделіп, есептеулерге енгізілді. Superpave әдістемесіне сәйкес жол жабынының температурасы 20 жылдық климаттық өзгерістерді талдау негізінде анықталады. Талдау нәтижесінде белгілі бір жылдағы қатарынан ең ыстық жеті күн ішіндегі орташа көлеңкедегі ауа температурасы 38,7 °C екені анықталды. Сонымен қатар, кез келген нақты жылда ауа температурасының осы мәннен жоғары немесе төмен болу ықтималдығы 50% екені белгіленді. Осыған байланысты жазғы есептік температураны тек 38,7 °C ретінде қабылдау орынсыз, себебі, мысалы, 14 жылдық кезеңде шамамен жеті жылда бұл көрсеткіштен жоғары температуралар байқалуы мүмкін. Сондықтан бұл параметр үшін қалыпты ықтималдық таралуын қабылдау дәл емес нәтижелерге әкеледі. Есептеулер Қазақстан аумағындағы асфальтбетон жабынына әсер ететін соңғы 20 жылдағы климаттық деректер негізінде жүргізілді. Superpave тұжырымдамасы аясында битумды байланыстырғыштардың реологиялық қасиеттерін және төмен температураға төзімділігін бағалауға арналған сынақ әдістері, қысқа мерзімді және ұзақ мерзімді тотығу арқылы қартаюды ескере отырып сипатталды. Бұл қасиеттер иілу арқалық реометрі (BBR) әдісімен анықталды. Сонымен қатар, минералды толтырғыштарға қойылатын сынақ талаптары мен олардың ерекшеліктері қарастырылып, асфальтбетон қоспасының құрамын, оның ішінде битумның оңтайлы мөлшерін анықтау әдістемесі талданды.

Түйін сөздер: битум, Superpave, реологиялық қасиеттер, жол құрылысы.

ТЕМПЕРАТУРА ДОРОЖНОГО ПОКРЫТИЯ И РЕЗУЛЬТАТЫ ИСПЫТАНИЙ, ПРОВЕДЁННЫХ ТРАДИЦИОННЫМИ МЕТОДАМИ

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Аннотация. Для выполнения всех экспериментальных процедур и расчётных анализов в соответствии с принятой методикой климатические условия Республики Казахстан были рассмотрены в качестве репрезентативного примера. На первом этапе была определена расчётная температура воздуха с заданным уровнем статистической надёжности. Для этого были обработаны и использованы метеорологические данные станций, расположенных вблизи исследуемой территории. Согласно методологии Superpave, определение температуры дорожного покрытия основано на анализе климатических колебаний за 20-летний период. В результате анализа установлено, что средняя температура воздуха в тени в течение семи последовательных самых жарких дней в году составляет 38,7 °C. При этом вероятность того, что в конкретном году температура воздуха окажется выше или ниже данного значения, составляет 50%. Следовательно, принятие летней расчётной

температуры только на уровне 38,7 °С является некорректным, поскольку, например, за 14-летний период примерно в семи годах могут наблюдаться более высокие температуры. Таким образом, допущение о нормальном распределении данного параметра приводит к неточным результатам. Расчёты были выполнены с использованием климатических данных за последние 20 лет, отражающих современные изменения климата, влияющие на асфальтобетонные покрытия в Казахстане. В рамках концепции Superpave описаны методы испытаний для оценки реологического поведения и низкотемпературной трещиностойкости битумных вяжущих с учётом как краткосрочного, так и долгосрочного окислительного старения. Эти свойства определялись методом изгибного балочного реометра (BBR). Кроме того, были рассмотрены требования к испытаниям и специфические характеристики минеральных наполнителей, а также проанализирована методика подбора состава асфальтобетонной смеси, включая расчёт оптимального содержания битума.

Ключевые слова: битум, Superpave, реологические свойства, дорожное строительство.