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An advanced method for the development of highly reliable asphalt concrete mixture

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ABSTRACT
This paper introduces the new technology of road construction pavement Superpave. From the beginning of the technology, the method of calculation of road pavement temperature has been taken as an example on the Shymkent city road in Kazakhstan. The material calculation for high quality was conducted with the new climate data of the exact city. A new methodological approach will determine the most accurate selection of bitumen binder grades using a specifically developed PG Grade calculation based on the meteorological data for the period from 2000 to 2020 (20 years) for the specific city. This will be intended to establish requirements for bitumen binders testing by the traditional method for both original and modified bitumen, such as penetration, softening point, and flash and fire point tests, taking into account the climatic characteristics of the republic. Today, have to be accounted that the most common bitumen binder is a 70-100 penetration rating, which means that quite incorrect to use at the highest temperature in Shymkent at +41.3°C and with the lowest temperature at -17.8°C. The results will help to decide on the use of polymer modification of binders, taking into account the design temperatures and operating conditions of asphalt concrete surfaces.
Keywords: bitumen grade, bitumen binder, Superpave, PG Grade calculations, Penetration grading, softening point, flash point.

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Introduction

Over the last few years, traffic on the roads of Kazakhstan and the world as a whole has increased significantly. At the same time, the number of vehicles and the traffic load on the roadway has increased, but with this load, road construction technologies themselves are growing much more slowly than necessary. To solve this problem, the government has decided to commission new roads and repair old ones. According to the road projects being implemented under the state programme "Nurly Zhol", almost all roads built will be provided with both asphalt and cement surfacing. Since the territory of Kazakhstan is subject to a sharply continental climate and the design of the pavement design must take into account for the climatic conditions of the construction area and the appropriate pavement material [[1], [2]].

As road maintenance practice shows, the durability of asphalt pavement is determined by its high plasticity, adhesion, and low-temperature properties as well as by its resistance to thermal oxidation aging.

Compared to closely related cement concrete pavements, they are also characterized by high evenness, good wheel grip, and the absence of expansion joints. All this ensures that not only individual vehicles but also all traffic can travel at the specified speed of up to 150 km/h and more [3].

For its part, the advantages of such pavements include dustlessness and quietness in vehicular traffic, low wear and tear (up to 1 mm per year), and easy maintenance and repair, although there are disadvantages such as increased slipperiness when wet and often short service life due to wave formation, shear due to lack of strength or excessive plasticity, cracking due to excessive brittleness and flaking due to insufficient water resistance. Considering the financial part, which is always perceived as a stimulus to domestic demand for the realization of economic growth, stable development of regions, and urban and rural settlements, the country still needs to carry out further scientific research.

The purpose of the review information is to provide a theoretical basis for an introduction to the scientific and technical developments regarding the improvement of pavement quality in Kazakhstan that has recently been published in the open press.

According to the World Economic Forum's 2017 Global Competitiveness Index, Kazakhstan ranked 115th out of 137 countries in terms of road infrastructure, between Russia and Zimbabwe. According to the information Kazakhstan needs this methodology [4].

Currently, according to the Road Committee of the MTC RK, the total length of Kazakhstan's roads is around 148,000 km, of which more than 93,000 km are public roads, divided into 23,495 km of national roads (including 12,992 km of international roads) and 70,116 km of local roads [4]. This indicates that most of the pavement is asphalt concrete, with the above-mentioned range of benefits, and needs to be improved in order to operate for a long period of time. For this purpose, our scientists such as B.B. Teltaev, E.D. Amirbayev, K.D. Sakanov, B.A. Asmatulaev, B.S. Murtazin etc. are engaged in research on the use of various new materials in construction. For the optimal solution in 2014, they stopped at the material warm asphalt concrete, which significantly reduces energy consumption, and gas emissions into the atmosphere and helps to prolong the construction season for high-performance asphalt concrete surface, also reminded to test polymeric additives in asphalt concrete that improve the properties of bitumen and bituminous emulsions.

The materials used for road construction must also be differentiated according to the characteristics of each road - both in terms of operating conditions and pavement design. For example, some roads are predominantly used by passenger cars, others by large vehicles. On some roads, the volume of traffic rarely changes throughout the year, in others, it depends on seasonal activities such as harvesting and transporting crops from agricultural enterprises [[5], [6], [7]]. For this reason, for each specific road, road builders develop individual asphalt mixes.

To ensure high-quality asphalt mixtures for highways, to make the best possible use of the effort and money invested in their construction - helps the US- Superpave methodology for creating best-performing asphalt pavements [8].

This methodology addresses problems such as classical deformation as well as resistance to fatigue and low-temperature cracking in Figures 1 and 2 [9].

Figure 1 - Classical deformation (rutting)

Figure 2 - Fatigue and low-temperature cracking

The Superpave system incorporates 3 interrelated components, successively updating the AASHTO and ASTM regulatory framework:

- SHARP - specifications and test methods for bitumen;

- Superpave - specifications and methods for the design of asphalt mixtures with mandatory determination of the pore characteristics of asphalt concrete samples at the different compaction stages;

- Test methods and a system for analyzing the rheological properties of asphalt concrete, focusing on the use of mathematical models of performance and computer software [10].

1. The specifications for bitumen binders and the corresponding rheological test methods are the most complete part of the implemented research programme. Not only the standard test methods have changed dramatically, but also the approach to the standardization of quality indicators of bitumen binders for asphalt mixtures. It is customary to characterize a bitumen binder grade by a temperature performance interval (PG Grade) which corresponds to the minimum and maximum design temperatures of the asphalt pavement in the construction region in question [11].

Experimental technique

Calculation of the pavement temperature. PG grade bitumen binder is determined on the basis of climate change for the last 20 years counting every 7-day average maximum design temperature (instead of the softening point temperature with ring and ball) and the minimum design temperature (instead of the Fraas embrittlement temperature). The maximum temperature which describes the heat resistance of bitumen binder can take values with a graduation of 6°C in the range from plus 46°C to plus 82°C. The minimum temperature for the low temperature properties of bitumen can take values in the range from minus 10 °C to minus 46 °C with the same gradation of 6°C. When selecting a binder grade, the requirements for deformability and viscoelastic properties remain unchanged, but the temperature range in which these requirements have to be fulfilled changes [[12], [13], [14], [15]].

Thus, when designing asphalt concrete mixtures, the bitumen binder grade is selected based on the climatic conditions and the purpose of the asphalt concrete pavement. With respect to the working temperature range for the 4 climatic zones of the USA, the following binder grades were taken as the basic ones: PG 52-28, PG 58-22, PG 58-16 and PG 64-10 [16].

The higher reliability indicated in the figure of 97.5 % means a correspondingly lower risk of selecting an unsatisfactory binder grade. In order to increase the reliability of selecting a satisfactory bitumen grade for the region in question from 50 % to 98 % it is necessary to reduce the low design pavement temperature by 6 °C and to increase the maximum design temperature by 4 °C. The assumptions that remain unchanged are the meteorological data recorded at the nearest weather station in previous years over a period of at least 20 years [17].

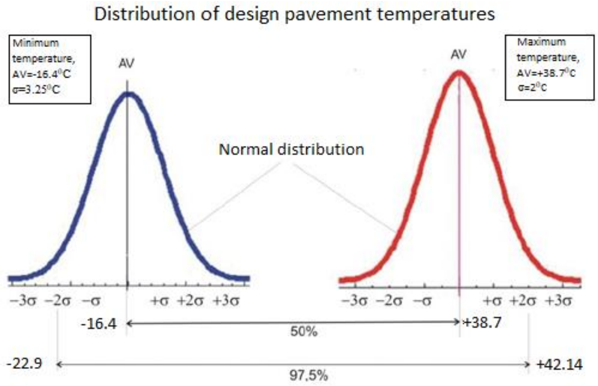


Figure 3 - Example of determining design pavement temperatures for selecting bitumen binder grades (AV-average temperature, σ- standard deviation)

To reduce the risk of plastic deformation in asphalt pavements in case of increased traffic loads as well as in braking areas, it is recommended to use bituminous binders of a higher heat-resistance grade.

Conventional Bitumen Test. Penetration, Ring and Ball Softening Point, Flash and Fire Point tests were used in order to investigate base bitumen and PMB respectively. A standardized needle with a weight of one hundred grams is used in the penetration test. The needle is given five seconds to make its way through the material while the load is being measured. The penetration of the needle into the substance being tested may be determined by the depth of penetration, which is represented in units of 1/10 millimeter. According to ASTM standard D5-13, the penetration grade of the bitumen that was tested is determined by the measurement taken at 25°C.

According to ASTM: D36-12, SP test method consists of determining the temperature at which bitumen, poured and cooled inside rings of given dimensions, under test conditions softens and, moving under the weight of a steel ball, touches the bottom plate.

As the temperature at which a steel ball lying on a bitumen film causes a deformation of 25,4 mm on bitumen.

The bitumen Flash and Fire Point tests provided by AASHTO Designation: T 48-06 or ASTM Designation: D 92-05a. The present test method consists of heating a sample of bitumen in an open cup at a prescribed rate until bitumen vapours flash over the surface of the cup from an ignition device.

Research Results and Discussion

Calculation of the pavement temperature. The city of Shymkent was considered as an example. Initially, the estimated air temperature at a certain reliability is found. Data from the nearest weather station is processed (Figure 3) The average shade air temperature for the 7 consecutive hottest days of the year over a 20-year period is 38.7℃. There is a 50% probability that it will either be higher or lower than 38.7℃ in any given year. It would not be correct to assume an estimated summer temperature of 38.7℃ because, for example, with a lifetime of 14 years there will be approximately 7 hotter years. Therefore, taking its probability distribution as normal data for 20 years, we find that the standard deviation of the air temperature of the hottest week in a given year is 1.71℃. Using the probability integral table, we find that a two-fold standard deviation corresponds to a reliability of 0.9772, i.e. approximately 98%. Then the calculated summer air temperature will be (38.7℃ +2℃*1.71)= 42.14℃ with a 98% reliability. This means that there may be a hotter summer about once every 50 years.

Similarly, we process observational data from the same weather station on the minimum daily winter temperatures, but here its variation is characterized by a standard deviation of 3.25℃ for a reliability of 98%. Thus, the low temperature is (-16.4℃-3.25℃*2)=-22.9℃. (Fig. 3)

Based on these air temperatures, it is possible to find the calculated pavement temperatures. Then the calculated summer temperature in the pavement at a depth of 2 cm from the surface is expressed by the formula:

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

where, $T_{air} -$ air temperature in shade, ℃; Lat —northern latitude in degrees, with solar radiation absorption coefficient 0.9; solar radiation transmittance coefficient 0.81; atmospheric radiation 0.7 and wind speed 4.5 m/s taken into account when deriving this formula.

$Lat - 42.18$ degrees north latitude of Shymkent and our found summer air temperature of 42.14℃, we obtain the calculated temperature of pavement in summer $T_{20mm} = 61{,}44$℃.

Taking the estimated winter temperature as the same as the air temperature creates an excessive reserve, according to Canadian researchers, and they have proposed a formula

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

By substituting it with the calculated minimum one-day air temperature of minus 22.9℃, we obtain the calculated winter cover temperature $T_{min} =$-17.9℃.

According to Table 1 in 6℃ increments we mark the binder, i.e. in our example we have to choose instead of 61.44℃ the nearest high temperature grade PG 64 and low temperature grade PG -22, i.e. for conditions of Shymkent city the binder grade PG 64-22. It turns out that in both cases the reliability is more than 99% as "rounding off" in 6℃ increments gave an additional margin. In view of this, however, our design air temperatures must be revised by reducing the required reliability and the design reliability of the resulting binder grade must be checked after the design pavement temperatures have been determined. As a rule, when the absolute difference between high and low design pavement temperatures is greater than 90°C, a polymer-bitumen binder must be used instead of bitumen.

Thus, the pavement temperature has to be calculated for each region separately, taking into account the individual climatic conditions. This is because, according to studies, temperatures have changed considerably over the last 10-20 years. In fact, all the media are reporting on the negative effects of its rise on society.

In our example of PG 64-22 this difference is (64-(-22))=86 and you can probably get by without modifying the polymer. But for PG 58-34, for example, it would be (58-(-34))=92, and the binder would probably cost about twice as much. According to Figure 4, which is taken from the Kazakhstan Highway Research Institute recommendation document, 80% of the republic needs a modification to bitumen which is up to 90. After recalculating the data, the percentage of regional modification bitumen might change, because there are differences in Shymkent city between our calculation with new weather data PG 64-22 and their calculation with 40 years past data PG 64-28 (purple region).

For each bitumen, the requirements for climatic operating conditions are determined, i.e. for resistance to rutting, fatigue failure, and low-temperature cracking at design operating temperatures.

Before testing, the binder is first subjected to artificial thin-film aging in an RTFO oven to simulate the short-term aging process during asphalt mix preparation, transportation and road laying and then to a high temperature and pressure (PAV) chamber to simulate the long-term oxidative aging process under years of pavement use. The dynamic shear rheometer test is then used to calculate the resistance to permanent deformation accumulation (rutting) and flexural fatigue of the pavement. It is intended to

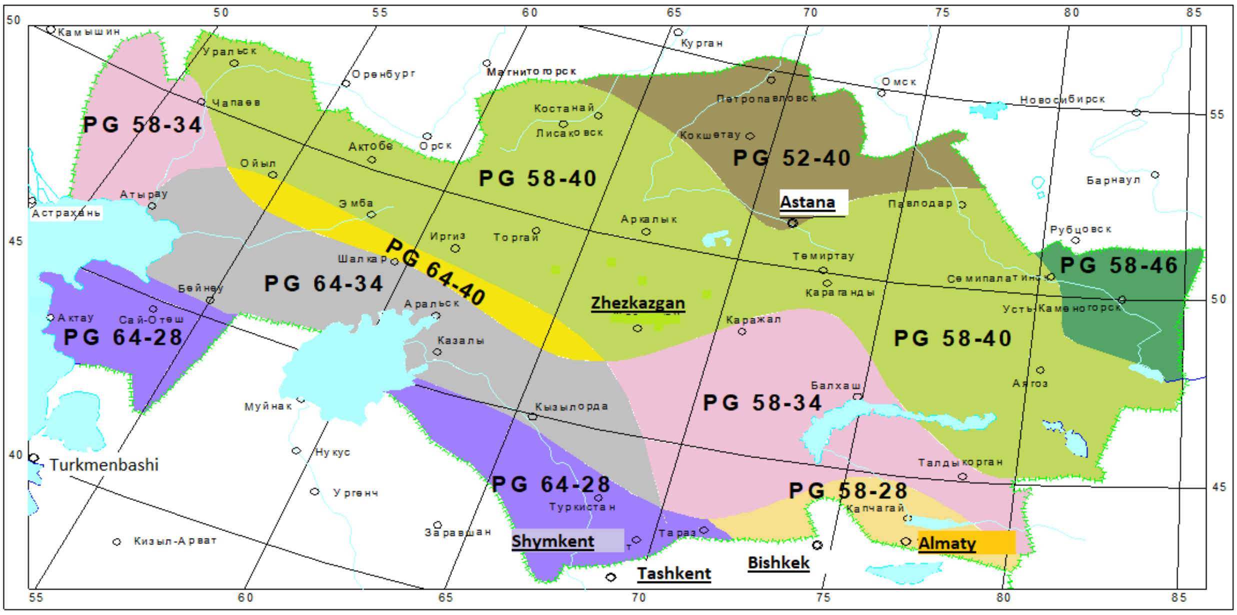


Figure 4 - Zoning map of Kazakhstan [10]

determine a complex shear modulus G* and phase angle δ of bituminous binders at design pavement temperatures. The tests are carried out according to the standard [[18], [19], [20]].

It can be seen from table 1 that the lowest temperature is minus 46°C and the highest is 82°C. In fact, in the northern states, the cover temperature can drop to minus 46°C, but there is no state where the average 7-day summer cover temperature reaches 82°C. It usually does not exceed 70°C.

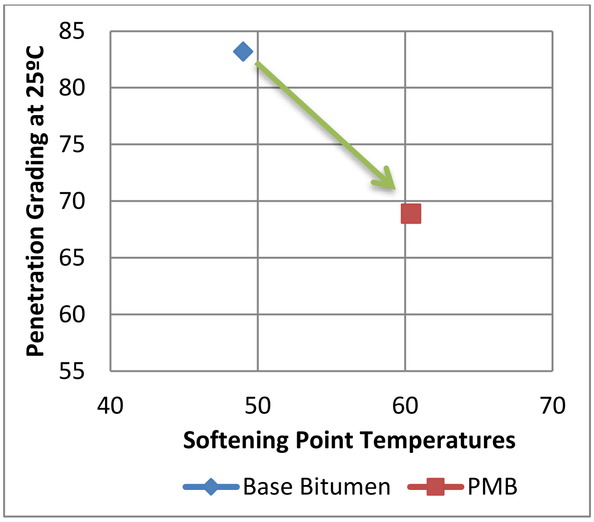
The point is that the grade of PG 64-22 indicates its suitability for 64°C summer design temperature and for winter design temperature of minus 22°C in fast-moving traffic (over 70km/h) of average intensity (up to 10 million axle passes with a design load of 80kN during the service life of the binder). But for sections with slow traffic (for example, for taxiways of airfields or for intersections), where the average speed is concluded within the limits of 20-70 km/h or for sections, where the number of passes during design load on one lane of roadway exceeds 10 million axles, it is recommended to choose the binder one grade (by 6°C) "hotter", i.e. in our example for Shymkent PG 70-22. If these conditions are combined, it is recommended that a two grades hotter binder is selected, i.e. PG 76-22.

For very slow traffic areas where the average speed does not exceed 20 km/h, two grades hotter, i.e. also PG 76-22, are selected. Therefore, an area with a realistic design summer pavement temperature of 70°C may require a maximum grade shift of 12°C, which is accounted for in the table by the introduction of PG 82 [[21],[22],[23],[24],[25]].

Table 1 - Binder grades according to operating conditions (PG)

High temperature grades, ^{0}C	**Low temperature grades, 0C**						
PG 46	-34	-40	-46				
PG 52	-10	-16	-22	-28	-34	-40	-46
PG 58	-16	-22	-28	-34	-40		
PG 64	-10	-16	-22	-28	-34	-40	
PG 70	-10	-16	-22	-28	-34	-40	
PG 76	-10	-16	-22	-28	-34		
PG 82	-10	-16	-22	-28	-34		

Conventional Bitumen Tests Results. In the study that was done on the qualities of base bitumen and PMB, the findings showed that using a polymer composition led to a considerable improvement in most of the indicators. This was discovered via the examination of those data. In particular, the needle's ability to penetrate bitumen at a depth of 25 °C is lowered by 14.3 millimeters. The temperature at Softening point test begins to soften and rises from 49 degrees Celsius to 60.4 degrees Celsius, which lessens the propensity of bitumen to distort. The Flash Point temperature also increased for 12 degrees. All tests results given in following graphs.



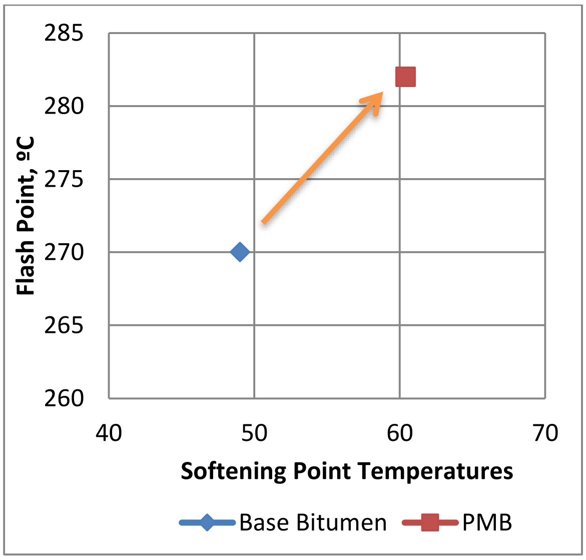


Figure 5 - Conventional Bitumen Tests Results

Figure 5 shows the results of penetration and softening point tests performed on bitumen. As can be seen in Figure 5, the penetration tended to decline to add any kind of polymer, here the Butonal NS was used as a polymer. With the addition of polymers, the bitumen's softening point increased, corroborating the penetration test results. These findings suggest that adding polymers to bitumen increases bitumen hardness significantly. However, because the bitumen gets harder following alteration, this is accompanied by a reduction in elastic recovery. Polymers, on the other hand, had an impact on bitumen's elastic characteristics, with the percentage of elastic recovery increases, the Butonal NS works well in increasing the recovery process between 85-95%. In terms of flash point testing, both the basic and polymer-modified bitumen samples were found to have values that were higher than the specified minimum of 220 ºC, on the other hand, there was still an increase with adding polymer.

Conclusions

Thus, in order to develop requirements for bitumen binder and asphalt concrete taking into account climatic features of the republic, as well as to make a decision on the use of polymer-bitumen binders and asphalt concrete on their basis taking into account design temperatures: its temperature in winter and summer, design traffic intensity and traffic flow rate of asphalt concrete surface calculations at 20 mm depth was studied. Furthermore, for the 64^{o}C pavement temperature of Shymkent city, just with traditional ways of testing bitumen it was obvious that base bitumen characterizes wouldn't work properly, and could not resist to road loads without adding polymer.

In Kazakhstan, in 2013 the Kazakhstan Highway Research Institute (KazdorNII) developed a recommendation which is called "Rezoning of Kazakhstan Territory by Design Temperatures for Asphalt Concrete Pavements". However, the information in this report is based on climate change between 1987-2006, i.e. it is not considered suitable for the preparation of asphalt concrete at present. The data needs to be recalculated using climate change data for the last 20 years to determine the composition of high-strength asphalt concrete pavements.

Conflict of interest. On behalf of all the authors, the correspondent author states that there is no conflict of interest.

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ТҮЙІНДЕМЕ
Бұл мақалада Superpave жол төсемдері құрылысының жаңа технологиясы ұсынылады. Технологияның басынан бастап жол төсемінің температурасын есептеу әдістемесі келтіріледі және мысал ретінде Қазақстандағы Шымкент қаласының жолы алынады. Жоғары сапалы материалды есептеу нақты осы қаланың жаңа климаттық деректерімен жүргізілді. Жаңа әдіснамалық тәсіл нақты қала үшін 2000 жылдан 2020 жылға дейінгі кезеңдегі (20 жыл) метеорологиялық деректерге негізделіп арнайы әзірленген PG бағасының есебін пайдалана отырып, битум байланыстырғыш сорттарын неғұрлым дәл таңдап анықтайды. Бұл республиканың климаттық ерекшеліктерін ескере отырып, енуге, жұмсарту температурасына, тұтану температурасына сынақтар сияқты бастапқы және модификацияланған битумға дәстүрлі әдіспен битумды байланыстырғыштарды сынауға қойылатын талаптарды белгілеуге бағытталатын болады. Бүгінгі таңда ең көп таралған битум тұтқыры 70-100 пенетрация дәрежесіне ие екенін, яғни оны Шымкенттегі ең жоғары температурасы +41,3°C және ең төменгі температурасы -17,8°C болып тұрғанда пайдалануға болмайтынын ескеру қажет. Нәтижелер асфальтбетонды беттердің есептік температуралары мен жұмыс жағдайларын ескере отырып, байланыстырғыш заттардың полимерлі модификациясын қолдану туралы шешім қабылдауға көмектеседі
Түйін сөздер: битум маркасы, битум байланыстырғыш, Superpave, PG Grade есептеулері, ену дәрежесі, жұмсарту температурасы, тұтану температурасы.

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Усовершенствованный метод разработки высоконадежной асфальтобетонной смеси

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АННОТАЦИЯ
В данной статье представлена новая технология строительства дорожных покрытий Superpave. С самого начала применения технологии, метод расчета температуры дорожного покрытия был взят в качестве примера на дороге города Шымкент в Казахстане. Расчет материала на высокое качество был проведен с учетом новых климатических данных именно этого города. Новый методологический подход позволит определить наиболее точный выбор марок битумного вяжущего с помощью специально разработанного расчета PG Grade на основе метеорологических данных за период с 2000 по 2020 год (20 лет) для конкретного города. Это будет направлено на установление требований к испытаниям битумных вяжущих традиционным методом как для оригинального, так и для модифицированного битума, таких как испытания на пенетрацию, температуру размягчения, вспышку и температуру возгорания,

с учетом климатических особенностей республики. На сегодняшний день приходится учитывать, что самое распространенное битумное вяжущее имеет степень пенетрации 70-100, а это означает, что совершенно некорректно использовать его при самой высокой температуре в Шымкенте +41,3°С и при самой низкой температуре -17,8°С. Полученные результаты помогут принять решение о применении полимерной модификации вяжущих с учетом расчетных температур и условий эксплуатации асфальтобетонных покрытий

Ключевые слова: марка битума, битумное вяжущее, Superpave, расчеты марки PG, градация пенетрации, температура размягчения, температура вспышки.

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