ANNOTATION

of thesis for Ph.D. degree by specialty
6M074500 "Transport construction" for the subject: "**Investigation of low-temperature characteristics for asphalt concretes and polymer asphalt concretes".**

The actuality of work. The Republic of Kazakhstan, located in 3 road-climatic zones, has a predominantly sharp continental climate. High summer temperatures require measures to be taken against the formation of rutting and abrupt waves on a pavement, while low winter temperatures are the cause of thermal cracking. Frequent temperature transitions through 0°C also impede the operation of asphalt concrete.

Due to the influence of low temperatures, so-called "frost" cracks form on the asphalt concrete pavement. The peculiarity of such cracks is that they appear several years after the completion of the road construction and are oriented perpendicular to their longitudinal axis. After a large number of freeze-thaw cycles, the complex stress exceeds the tensile strength of the asphalt mix, which leads to the appearance of cracks and other obvious deformations.

All over the world, research is constantly being carried out to create new modern road materials and technologies, to adjust and improve the regulatory requirements for their physical and mechanical properties. All this is aimed at increasing the durability of road surfaces in modern conditions of their operation.

An effective way to improve the performance of bitumen and asphalt concrete is to modify them with polymer additives to increase heat resistance, lower Fraas point, and expand the temperature range of the material. Various additives have found wide application in the practice of road construction and repair in many countries.

The low-temperature characteristics of bitumen and polymer bitumen binder are widely studied, and there are requirements for the Superpave system.

However, the effect of low temperature on the distribution of tensile stresses and strains in the asphalt concrete layer remained undiscovered.

The idea of the work is to use the results of experimental and theoretical studies, and technical solutions for the use of modifiers in bitumen when designing asphalt concrete in the construction and repair of highways, taking into account operating conditions at low temperatures.

The target of thesis research is road asphalt concretes and polymer asphalt concretes.

The subject of thesis research. Low-temperature characteristics of asphalt concrete and polymer asphalt concretes.

Research objective.

Experimental study of low-temperature characteristics of asphalt and polymer asphalt concretes.

To achieve this goal, the following **tasks** are solved:

1. To determine the standard characteristics of conventional asphalt concrete;

2. To prepare polymer asphalt concretes with various polymer additives and determine their standard characteristics;

3. Testing by the device “TRAVIS 20-6000” the low-temperature characteristics of asphalt concrete and polymer-asphalt concrete shall be determined;

4. To determine the low temperature characteristics of bitumen binders by means of a bending beam rheometer (BBR) test.

5. To compare the climatic temperatures of bituminous binders, asphalt concrete, and polymer asphalt concretes with the experimentally determined values;

6. Based on the analysis of the results obtained, develop recommendations for their use in practice.

The scientific novelty of work is in the following:

- in Kazakhstan, for the first time, low-temperature characteristics (strength, failure strain, climatic stress, and critical temperature) of asphalt concrete used in road construction were determined;
- by modification with different polymers, polymer asphalt concretes are obtained and their low-temperature characteristics are determined;
- low-temperature characteristics (stiffness and relaxation rate, critical temperature) of bitumen and polymer bitumen used for the preparation of the asphalt concrete and polymer asphalt concretes were determined;
- it has been experimentally determined that modification with polymers increases the low-temperature characteristics of asphalt concrete;
- critical temperatures of bitumen binders, asphalt concretes and polymer asphalt concretes are approximately the same.

Introduction of research findings

Based on the research results of the thesis, the INNOBILD Limited Liability Partnership (INNOBILD LLP) has developed the national standard of the Republic of Kazakhstan ST RK EN 12697-46-2019 “Bituminous mixtures. Methods of testing for hot asphalt concrete mixtures. Part 46. Determination of Low-Temperature Cracking and Properties at Uniaxial Tensile Test”.

Reliability of research findings

Reliability of the obtained results is supported by the following provisions:

- all laboratory tests were carried out in the certified laboratory of KazdorNII JSC (Accreditation Certificate No. KZ.T.02.0603 dated 08.04.2020);
- modern methods of analysis with the application of the certified instruments were used (verification certificates are presented in appendices);
- to evaluate the behavior of bitumen binders at low temperatures, the device “Bending Beam Rheometer (BBR)” was used (certificate is presented in the Appendix);
- roller compactor of the company “Copper Research Technology Limited” (Great Britain) CRT-RC2S/ RC2S V complying with the requirements of the standard EN 12697-31. Bituminous mixtures-Test methods for hot mix asphalt - Part 31: Specimen preparation by gyratory compactor (certificate is enclosed) was used for compression of the asphalt concrete samples;
- for the determination of low-temperature stability of asphalt concrete, the device “TRAVIS 20-600” (Germany), meets the requirements of the standard pr. EN 12697-46 “Asphalt concrete mixtures. Methods of testing hot asphalt concrete mixtures. Part 46: Determination of Low-Temperature Cracking and Properties by Uniaxial Tensile Tests” (certificate is enclosed) was used;

- through multiple repeatabilities of the experiments characterized by high reproducibility of the results;

- lack of inconsistency of the results to basic laws of physics and chemistry.

The practical relevance of work

- methods and results of experimental determination of low-temperature characteristics of asphalt concrete and polymer asphalt concrete of thesis can be used in practice to evaluate the suitability of asphalt concrete and polymer asphalt concrete compositions in different climatic regions of the republic;

- the above methods are systematically used in the JSC KazdorNII to evaluate low-temperature characteristics of asphalt and polymer asphalt concretes;

- based on the testing of the above methods in the JSC KazdorNII and the experimental results obtained from them, the standard ST RK EN 12697-46-2019 "Determination of low-temperature cracking and properties during uniaxial tensile testing" was introduced in Kazakhstan.

- the results of the thesis were taken into account when developing the road departmental regulatory document R RK 218-129-2016 "Album of rational road pavement structures taking into account natural and climatic conditions and road categories.

The author's personal contribution consists in the analysis of scientific literature on studies of the low-temperature characteristics of various types of asphalt concrete, setting the goal and objectives of the work on the study of low-temperature stability, analyzing the results obtained on the effect of negative temperature on various types of asphalt concrete and polymer asphalt concrete with various polymers, publishing scientific articles on the topic of the thesis. The results of the studies are original and obtained personally by the author or with his direct participation.

Publications. On the topic of the thesis, 5 scientific papers were published, particularly 2 articles in journals included in the list of CCES of the Ministry of Education and Science of the Republic of Kazakhstan, 3 articles in journals included in the Scopus, and Web of Science databases.

Structure and scope of work. The thesis consists of five sections, findings (conclusion), appendices, and a list of the used references, including 93 titles of works by national and foreign authors. The work is presented on 120 pages of typewritten text, it contains 53 figures and histograms, and 3 tables.

The following items are submitted for the defense:

1. Selection of bitumen, standard physical and mechanical properties of bitumen, physical and mechanical properties of bitumen after short-term and long-term aging;

2. Selection of polymers for bitumen modification, the technology of polymer bitumen preparation, physical and mechanical properties of polymer bitumen;

3. Preparation of asphalt concrete and polymer modified asphalt concrete, determination of standard indicators of both asphalt concrete and polymer modified asphalt concrete;

4. Testing of bitumen binders at low temperatures;

5. Low-temperature characteristics of asphalt concrete and polymer-modified asphalt concrete;

6. Testing of asphalt concrete with uniaxial tensile stress;

7. Testing of asphalt concrete by temperature stress in the presence of end deformations;

8. Comparison of critical temperatures of bitumen binders and asphalt concrete.

THE MAIN CONTENT OF THE WORK

The dissertation research is aimed at investigating and analyzing the low-temperature properties of asphalt concrete and polymer-modified asphalt concrete.

Asphalt concrete is one of the most complex building materials. This complexity is mainly due to the peculiarities of its structure, as well as the large dependence of properties on various factors. The physical and mechanical properties of asphalt concrete change very dramatically with temperature changes. This feature of its properties distinguishes it from other road-building materials used in road construction.

In the first section, the analysis of the scientific literature on studies of low-temperature characteristics for various types of asphalt concretes and polymer asphalt concretes, the current state of study for the research issue and the formulation of the own research, the study of the world and national experience were carried out.

The main conclusions of **the first section are:**

- The study of the process of structure formation in asphalt concrete has shown that it is determined by the properties of mineral materials, but to a greater extent by the properties of bulk and structured bitumen;
- The study of the modern approach to the purpose of bitumen in order to standardize the structure of the asphalt concrete resistant to low-temperature cracking made it possible to determine the requirements that bitumen should meet;
- Bitumen shall ensure normal operation of an asphalt concrete pavement on the territory of the Republic of Kazakhstan and comply with the design temperatures of asphalt concrete pavements in the construction region regarding heat resistance;
- The study of the world and national experience has shown that it is possible to achieve this conformity by using polymer modifiers.

In the second section the analysis and the selection of a bitumen binder were carried out, the most important factors were determined in laboratory conditions, which should be taken into account when choosing the bitumen grade, consistency (viscosity), which is characterized by an indicator of penetration value and softening point. The choice of bitumen and bitumen grade is justified by the available results of the testing for the asphalt concrete used and demonstrated at the JSC KazdorNII. Standard physical and mechanical parameters of bitumen were determined as well.

The main conclusions of the second section are:

1. The bitumen of grades 100/130 and 130/200 manufactured by Pavlodar Petrochemical Plant (PNHZ) were selected for the research. The bitumen was produced from crude oil of Western Siberia (Russia) by direct oxidation.

2. The selected bitumens of grades 100/130 and 130/200 meet all the requirements of ST RK 1373 regarding physical and mechanical properties.

In the third section, the results of the works on the selection of polymers for modification of bitumen, as well as the technology for modifications of polymer bitumen binder, standard physical and mechanical indicators of the polymer bitumen binder for compliance with the RD were determined, the histograms were constructed. Analysis of the results for determining the main standard bitumen indicators of the grades 100/130 and 130/200 and modified with polymers was carried out.

The main conclusions of **the third section are:**

The analysis of the results for determining the fundamental standard bitumen indicators of grades 100/130 and 130/200 and modified with polymers, performed in this work, showed the following:

1. When added to bitumen, the polymers' penetration is decreased, thereby changing the bitumen grade. It is found that after modification 5 polymer bitumens are transferred to the next grade, 3 of them change the grade to 2 units, of which 1 bitumen has a grade more viscous by 3 units;

2. All polymers discussed above to increase the softening point, thereby improving the high-temperature stability of the bitumen;

3. Most polymers increase Fraas point (they decrease low-temperature stability). In two out of ten cases, the modification practically does not change the Fraas point. In only two cases of modification of the bitumen of grade 130/200 a positive effect was obtained - a decrease in Fraas point;

4. Only one case (43%) of modification showed an increase in the ductility of the bitumen. In other cases, the ductility is reduced.

In the fourth section, the work was carried out on the selection of asphalt concrete and polymer asphalt concrete with the determination of standard physical and mechanical indicators with the construction of a histogram for comparative analysis by laboratory measurements.

The main conclusions of **the fourth section are:**

1. Water saturation of polymer asphalt concretes is significantly lower than that of asphalt concrete, which shows the increased water resistance of polymer asphalt concretes.

2. Modification by polymers significantly increases the strength of polymer asphalt concretes at the temperature of 50 ^{0}C, which indicates higher stability of polymer asphalt concretes at high temperatures.

3. Practically all polymers used increase the shear resistance of the polymer asphalt concretes at the temperature of 50 ^{0}C.

4. The polymer additive Butanal NS 189 has been found to markedly increase the crack resistance of the polymer asphalt concrete at 0^0C.

In the fifth section, the work was carried out on the experimental determination of the characteristics of bitumen binders, asphalt concrete, and polymer asphalt concrete at low temperatures. Preparatory works were carried out for the bitumen and the asphalt concrete for laboratory studies according to a non-standard method. The methods for determining the low-temperature characteristics of the bitumen binder and the asphalt concrete on special devices are described. The results of testing the low-temperature characteristics of bitumens, asphalt concretes and polymer asphalt concretes are given. Histograms were constructed and a comparative analysis of the results for the critical temperatures of bitumen binders and asphalt concretes was carried out.

The main conclusions of **the fifth section are:**

1. The relaxation rate of the original and modified bitumen tests for low-temperature properties on the device BBR at all tested temperatures (-24°C, -30°C, and -36 °C) is higher than the required minimum value of 0.3. This fact suggests that in the case of oxidized bitumens, according to the Superpave system criterion, the relaxation rate does not work;

2. The stiffness of all tested bitumen binders at the temperatures of -24°C and -30°C is significantly lower than the permissible maximum value of 300 MPa. At -36°C, only the original bitumen of grade 130/200 and the bitumen of grade 100/130 with Calprene polymer meet the Superpave requirement;

Critical temperature values, when a binder has permissible maximum stiffness (300 MPa), range from -32.2°C to -38.2°C. For most tested bitumen binders, the critical temperature varies within relatively narrow limits (from 33.8°C to 36.7°C). The exception is only the bitumen of grade 130/200 modified with Kraton polymer (-33.2°C) and Butonal polymer (-33.1°C);

3. When deforming at a constant rate at the temperature of -10°C, the strengths of the tested asphalt concrete are close in value: 5.1-6.0 MPa. With the decrease in temperature, the difference in strength values of different types of asphalt concrete becomes more noticeable. Thus, the strength of the asphalt concrete at temperatures of -20°C and -30°C varies from 4.8 MPa to 7.6 MPa and from 4.1 MPa to 7.0 MPa, respectively.

Modification of bitumen by polymers gave a positive effect at the temperatures of -20°C and -30°C;

4. The results of testing for the asphalt concretes according to the sample test scheme under the influence of temperature stresses under restriction (TSRST) indicate that the modification of bitumen by polymers increases the characteristics of low-temperature stability of the asphalt concrete. For different polymers, the decrease in critical temperature from 2.2°C to 4.9°C was obtained;

It turned out that the effect of modifying bitumens with polymers is more revealed in critical stress values. It follows from the analysis of the test results that the maximum increase in critical stress can be more than 80%.

3. It has been determined that the values of the critical temperature of bitumen binders and the critical temperature of the corresponding asphalt concretes are almost the same.

Conclusion

1. The results obtained in the current dissertation can be linked to the previously established low-temperature requirements for bitumen binders, taking into account the climatic features of the republic, and can also be used to make a decision on the use of polymer-bitumen binders and asphalt concrete based on them, taking into account the calculated temperatures and operating conditions of asphalt concrete pavement.

2. The rationale for using polymer additives to increase the low-temperature crack resistance of asphalt concrete has been experimentally proved. Experimental data and dependences determining the low-temperature stability of polymer modified asphalt concrete at critical temperatures have been obtained.

3. The research results make it possible to design asphalt concrete according to low-temperature properties corresponding to climatic operating conditions.

4. The results obtained make it possible to improve the characteristics of the road surface by using a modified asphalt-concrete mixture in the layers of pavement. This provides an alternative approach to extending the service life of the pavement in addition to the existing practice, mainly using a polymer modified asphalt mixture.

5. The data obtained with the use of polymer additives and different compositions of asphalt concrete mixtures will help to gain experience and can be used in the future when calculating and normalizing the characteristics of asphalt concrete mixtures and bitumen binders.

LIST OF PUBLICATIONS

1. B.B. Teltayev, C.O. Rossi, G.G. Izmailova, E.D. Amirbayev, A.O. Elshibayev. Журнал «Case Studies in Construction Materials» ELSEVIER (11) 2019. Статья: Case study Evaluating the effect of asphalt binder modification on the low-temperature cracking resistance of hot mix asphalt.

2. Ельшибаев А.О., Г.Г. Измаилова, Н.Н. Сарыбаев. Статья: Определение низкотемпературного трещинообразования теплых и ресайклированных асфальтобетонов. Вестник: «Казахской академии транспорта и коммуникаций имени М.Тынышпаева» ISSN 1609-1817 №2 (105)-2018, стр. 175-181.

3. Ельшибаев А.О., Г.Г. Измаилова, Е.С. Сивохина. Статья: К вопросу применения битумной эмульсии в составе Ресайклированного слоя. Вестник: Казахской академии транспорта и коммуникаций имени М.Тынышпаева ISSN 1609-1817 №2 (105)-2018, стр. 182-188.

4. Ельшибаев А.О., Г.Г. Измаилова. Статья: Оценка устойчивости колееобразования теплых и традиционных асфальтобетонов. Вестник: Казахской академии транспорта и коммуникаций имени М.Тынышпаева ISSN 1609-1817 №2 (105)-2018, стр. 205-210.

5. М. Ж. Журинов, Б. Б. Телтаев, С. О. Росси, Ельшибаев А.О., Е. Д. Амирбаев Статья: Стандартные показатели модифицированных битумов. N E W S OF THE

NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN SERIES OF GEOLOGY AND TECHNICAL SCIENCES ISSN 2224-5278 Volume 5, Number 443 (2020), 188 – 195.
6. М. Ж. Журинов, Б. Б. Телтаев, Ельшибаев А.О., Е. Д. Амирбаев Статья: Определение низкотемпературного трещинообразования асфальтобетонов. N E W S OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN SERIES OF GEOLOGY AND TECHNICAL SCIENCES ISSN 2224-5278 Volume 6, Number 444 (2020), 261 – 267.
7. Ельшибаев А.О., Г.Г. Измаилова. Статья: Определение низкотемпературного трещинообразования асфальтобетонов В сборнике научных трудов седьмой международной научно-практической конференции «Автомобильные дороги и транспортная техника: проблемы и перспективы развития» 08 февраля 2019 года «Казахская автомобильно-дорожная академия им. Л.Б. Гончарова». УДК 625.7/.8:691.168ББК 39.331:74.58, Стр. 33-38.
8. Ельшибаев А.О., Г.Г. Измаилова. Статья: Определение низкотемпературного трещинообразования ресайклированных асфальтобетонов. В сборнике научных трудов седьмой международной научно-практической конференции «Автомобильные дороги и транспортная техника: проблемы и перспективы развития» 08 февраля 2019 года «Казахская автомобильно-дорожная академия им. Л.Б.Гончарова». УДК 625.7/.8:691.168 ББК 39.331:74.58, Стр. 39-44.