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Original scientific papers

Evaluation of low-temperature properties of mixtures of bitumen and SBS polymers of various topologies by the ABCD method

Оценка методом ABCD низкотемпературных свойств смеси битумов и СБС-полимеров различной топологии

Процена нискотемпературних својстава смеше битумена и SBS полимера различитих топологија методом ABCD

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Acceso abierto diamante

Abstract

Introduction: Due to climate change, scientists around the world, including specialists in the road construction industry, are forced to take into account the need for regular monitoring of the low-temperature properties of both individual building materials and the properties of multicomponent road composites based on them. Therefore, the possibility of developing new approaches and methods for evaluating these properties is being studied.
Methods: For these purposes, Dr. Kim Sang-Soo proposed a new method for evaluating the low-temperature properties of road binders, which was called the ABCD (Asphalt Binder Cracking Device) method. The use of the device does not require special skills and knowledge and auxiliary equipment is widely available in laboratories of road construction organizations. The duration of the test does not exceed 4-5 hours.

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Results: The possibility and effectiveness of regulating the cracking temperature of bitumen-containing binders by introducing styrene-butadiene thermoplastics of various topologies into the composition is shown using the example of industrially produced batches of petroleum road viscous oxidized bitumen and applying the ABCD methodology.
Conclusions: In Russia, where winter temperatures in the vast majority of the country fall below minus 30 degrees Celsius, it is extremely important to control the behavior of bitumen binders and multicomponent mixtures of different compositions (asphalt concrete mixtures). The national standard GOST R 58400.11-2019 has been put into effect and the production of appropriate measuring equipment has been established. At the same time, the ABCD method can be used both to study the properties of mixtures of binders with polymers of various topologies and to select a commercial binder that meets the requirements of a specific region of highway operation.
Keywords: cracking temperature, polymer-modified bitumen, ABCD method, styrene-butadiene thermoplastics of various topologies.

Резюме

Введение: В связи с изменением климата ученые всего мира, в том числе специалисты дорожно-строительной отрасли, вынуждены принимать в расчет необходимость регулярного контроля низкотемпературных свойств как отдельных строительных материалов, так и свойств многокомпонентных дорожных композитов. Поэтому изучается возможность разработки новых подходов и методов оценки указанных свойств.
Методы: Для указанных целей доктор Kim Sang-Soo предложил новый метод оценки низкотемпературных свойств дорожных вяжущих, который получил название метод ABCD (Asphalt Binder Cracking Device). Использование прибора не требует специальных навыков и знаний, а вспомогательное оборудование широко доступно в лабораториях дорожно-строительных организаций. Продолжительность испытания не превышает 4-5 часов.
Результаты: На примере промышленно выпускаемых партий битумов нефтяных дорожных вязких окисленных марки БНД 70/100, с применением методологии ABCD по ГОСТ Р 58.400.11-2019, показана возможность и эффективность регулирования температуры растрескивания битумосодержащих вяжущих путем ввода в состав композиции бутадиен-стирольных термоэластопластов различной топологии.
Выводы: В России, где зимние температуры на подавляющей территории страны опускаются ниже -300 ^{0}C, крайне важна доступность контроля поведения битумных вяжущих и многокомпонентных смесей разного состава (асфальтобетонных смесей). Введен в действие национальный стандарт ГОСТ Р 58400.11-2019 и налажено производство измерительного оборудования. При этом метод ABCD может быть использован как для изучения свойств смесей вяжущих с полимерами различной топологии, так и для выбора товарного вяжущего, соответствующего требованиям конкретного региона эксплуатации автомобильной дороги.
Ключевые слова: температура растрескивания, полимерно-битумные вяжущие, метод ABCD, бутадиен-стирольные термоэластопласты различной топологии.

Abstract

Увод: У вези са климатским променама, научници широм света, укључујући стручњаке из области изградње путева, приморани су да узму у обзир потребу за редовном контролом нискотемпературних својстава појединих грађевинских материјала и својстава вишекомпонентних композита на њиховој бази. Због тога се проучава могућност развоја нових приступа и метода процене наведених својстава.
Методе: Ким Санг-Су је предложио нову методу за процену својстава везивних материјала за изградњу путева при ниским температурама, коју је назвао ABCD метода (Asphalt Binder Cracking Device). Употреба уређаја не захтева посебне вештине и знања, а помоћна опрема је широко заступљена у лабораторијама компанија за изградњу путева. Испитивање не траје дуже од 4 до 5 сати.
Резултати: На примеру производње индустријских серија нафтних путних вискозних оксидованих битумена марке БНД 70/100, уз примену ABCD методе у складу са стандардима ГОСТ Р 58.400.11-2019, приказана је могућност и ефикасност регулисања температуре пуцања везива у битумену увођењем у његов састав стиренско-бутадиенских термопластичних еластомера различитих топологија.
Закључци: С обзиром на то да зими у већем делу Русије температуре падају испод -30^{0}C, веома је важно омогућити регулисање понашања битуменских везивних и вишекомпонентних смеша различитог састава (асфалтно-бетонске смеше). Утврђен је национални стандард ГОСТ Р 58400.11-2019 и успостављена је производња мерне опреме. ABCD метода се може истовремено користити како за проучавање својстава везивних смеша на бази полимерима различитих топологија, тако и у одабиру везива у комерцијалне сврхе, која морају задовољавати прописе за изградњу ауто-путева конкретног региона у којем ће се користити.
Keywords: температура пуцања, полимер-модификовани битумен, ABCD метода, стиренски бутадиен термопластичних еластомера различитих топологија.

Introduction

Low-temperature cracking of asphalt pavement is understood as transverse cracks occurring at approximately equal distances at right angles to the direction of travel (Flory, 1985). It is assumed that binders with higher stiffness will crack at higher temperatures than softer bituminous binders (Gokhman, 1977; Nazzal et al, 2014; Petersen et al, 1994; Plewa, 2019).

To date, no sound methodology or direct measurement method has been developed in the world that can accurately determine the low-temperature properties of binders based on tests performed at much higher temperatures, such as under normal conditions.

That is why of great practical interest are the so-called direct measurement methods which reproduce the loading conditions of materials or structures as close to reality as possible. The data obtained in the course of such tests are a reliable basis for predicting the real performance properties of both raw material components and multicomponent materials based on them.

An example is the ABCD (Asphalt Binder Cracking Device) method of evaluating the low-temperature properties of road bitumen, developed during many years of research by Dr. Kim Sang-Soo, a professor in the Department of Civil Engineering at Ohio University (Kim, 2005, 2007; Petersen 1994).

The feature of this fundamentally new for the Russian road industry test method is the ability to determine the potential of low-temperature cracking of bitumen binders without prior analysis or knowledge of the rheological properties of bitumen binders (Nebratenko, 2022).

When the temperature of the pavement decreases under actual operating conditions, shrinkage and cracking of the asphalt concrete pavement as a whole and, above all, of bituminous binders, takes place. In this case, the binder acts as a glue in the composition of the pavement and, under certain conditions, the monolithic adhesive layer between the particles of stone aggregate is broken.

The ABCD test is carried out as follows: a sample of a bituminous (often polymer-bitumen) binder is placed in a cryochamber and the temperature of the air surrounding the tested sample is gradually reduced, causing similar thermal compression until a transverse crack is formed (Nebratenko & Nikolaevsky, 2023).

Methodology for assessing the properties of mixtures based on semi-blown road bitumen and SBS polymers

Let us illustrate the possibility of assessing the low-temperature properties of mixtures based on semi-blown (oxidized) oil road bitumen and SBS-polymers of different molecular structures by the ABCD method. This will make it possible to evaluate the advantages of a number of modifiers used to improve the low-temperature properties of road binders.

Bitumen basic compositions were industrially produced oil oxidized road bitumen BND 70/100, conforming to GOST 33133-2014 (Table 1).

Table 1

Physical and mechanical properties of semi-blown viscous road petroleum bitumen

№	Name of the indicator	Actual values for BND 70/100	Test methods of bitumen (Interstate standard, GOST)
1	Penetration at the temperature of 25°C, [0.1 mm]	90	GOST 33136
2	Penetration at the temperature of 0°C, [0.1 mm]	34	GOST 33136
3	Ductility at 25°C, [cm]	90	GOST 33138
4	Softening point (ring and ball), [°C]	50	GOST 33142
5	Fraass breaking point, [°C]	- 18	GOST 33143
6	Flash point (Cleveland open cup), [°C]	271	GOST 33141

Таблица 1 – Физико-механические свойства битума нефтяного дорожного вязкого окисленного

Табела 1 – Физичко-механичка својства нафтног путног вискозног оксидованог битумена

Polymers in the amount of 3% wt. were introduced in equal portions into the base bitumen heated to a temperature of 140-160 ^{0}C. During the first 15 minutes, the mixture was mixed with a laboratory dispersant IKA Ultra-Turrax T25 digital at a rotor speed of about 10,000 revolutions per minute. Then the aging stage (swelling) took place for 2.5 hours at a rotor speed of 3,000 revolutions per minute and a temperature of 60-80 ^{0}C.

The ABCD cracking machine is one of the few devices that determine the indicator of the binder not indirectly, but by a direct method. This significantly differs, for example, from the well-known method “Ring and Ball” according to GOST 11506 or GOST 33142.

The measuring part of the device consists of a metal ring of Invar, equipped with temperature and deformation sensors, The metal ring with sensors is placed in an elastic silicone rubber shell (Fig. 1). After the heated bitumen binder is poured into the gap between the ring and the casing and solidifies, the samples (one control and three test samples) are placed in a cryochamber (Kim, 2007; Nebratenko & Nikolaevsky, 2023).

Figure 1

ABCD sensors during (left) and after (right) testing of binders

Рис. 1 – Датчики ABCD во время (слева) и после (справа) проведения испытаний вяжущих

Слика 1 – АБСД сензори током (лево) и након (десно) тестирања везива

When the temperature drops, the bitumen binder shrinks more than the metal ring of Invar. Invar is a specially selected alloy composed of nickel (Ni, 36%) and iron (Fe, 64%) and has a uniquely low coefficient of thermal expansion. This makes it possible to keep its geometrical dimensions unchanged in the widest temperature range from minus 90 up to plus 250°C. Invar's coefficient of thermal expansion is only 1.2·10-6 °C (Nebratenko, 2022).

When bitumen or the binder cools, thermal deformations lead to changes in the strength, stiffness and thermal compression coefficient. The temperature and stress level at which the continuity of the test samples is broken are recorded automatically. This makes it possible to determine the degree of suitability of the investigated binder type for its use in the course of construction or repair of road surfaces in the natural and climatic conditions of subsequent operation expected in a particular region of Russia as reliably as possible.

The results of measurements of the studied parameters reflecting the low-temperature properties of road bitumen binders of different types, including those containing SBS-polymers, are presented in Table 2.

Table 2 shows the low-temperature values determined by the ABCD method for several binders, including SBS-polymer-based PMBs of different structures.

Table 2
Low-temperature indicators of bituminous binders

Binder	Cracking temperature of ABCD, °C	Fraass breaking point, °C	Deformation spike, με	Breaking stress, MPa
BND70/100	-36.41	-18	16.58	2.61
PMB 60 to SBS-330L	-44.96	-24	31.27	5.05
PMB 60 to SBS-330B	-41.14	-22	20.05	3.48

Таблица 2– Низкотемпературные показатели битумных вяжущих
Табела 2 – Нискотемпературни показатељи битуменских везива

The 15-30% decrease in the cracking temperature for ABCD polymer-bitumen compared to the data for basic bitumen can be explained by the presence of a three-dimensional elastomeric mesh in the volume of polymer-bitumen binder. There is, due to its presence, a dissipation of deformations resulting from temperature stresses during cooling of the binder.

The graph in Fig. 2 shows that when the temperature drops below minus 30 °C, excessive residual temperature deformations accumulate in the volume of the PMB, the dissipation of which even in elastic blocks of SBS polymers is prevented by the low rate of relaxation. It should be noted that cooling of the system is carried out at rather low speeds corresponding to the requirements of GOST R 58400.11-2019 "Public Roads, Petroleum Bituminous Binder Materials, Method for Determining the Cracking Temperature Using the ABCD Device" and corresponding to the actual operating conditions in the regions of the Russian Federation.

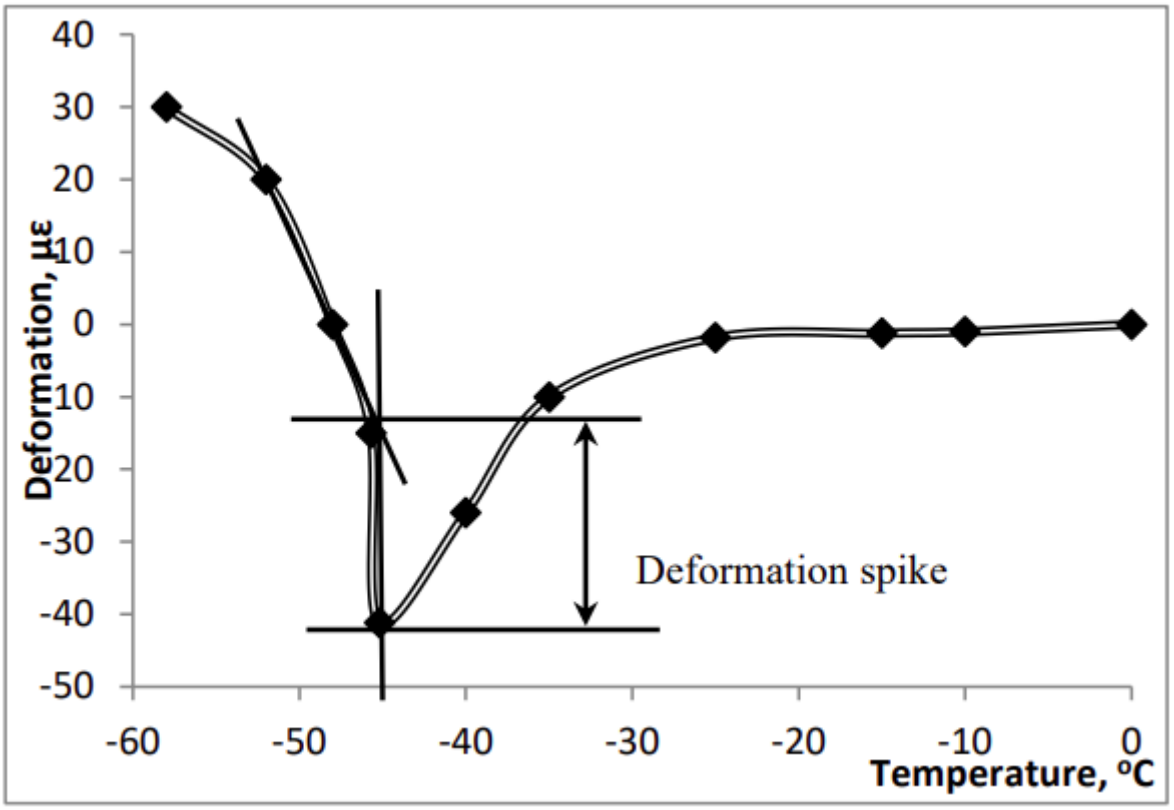

Figure 2

Temperature dependence of deformation for polymer-modified bitumen PMB 60 in case of using SBS-330L as a modifier

Рис. 2 –Температурная зависимость деформации полимерно-битумного вяжущего ПБВ 60 при использовании в качестве модификатора SBS-330L

Слика 2 –Температурна зависност деформације полимерно-битуменског везива ПМБ 60 када се користи СБС-330Л као модификатор

When the critical temperature reaches minus 44.96 °C, there is a sharp spike in deformation and destruction of the binder film, and the stress of its destruction is 5.05 MPa. Therefore, the subsequent decrease in temperature has no significant effect on the deformation properties of the destroyed binder sample, and the PMBs behave as conditionally solid bodies (Mieczkowski et al, 2021; Nebratenko & Nikolaevsky, 2023).

It should be noted that the above figures are given for the case of using linear SBS-polymer as a modifier. In the case of using the brand of branched polymer SBS-330B, the cracking temperature of the binder is higher and the strain jump is noticeably, almost 45%, lower. This correlates well with the previously presented theoretical justifications and practical data on the effectiveness of butadiene styrene thermoplastic elastomers as modifiers of bitumen binder properties (Nebratenko, 2022; Hesp, 2004).

Results

Thus, as a result of the direct determination of the cracking temperature of polymer-bitumen and bitumen binders of various compositions, the influence of the topology of the SBS polymer on the low-temperature properties of a multicomponent road binder was established. Polymers of linear structure, with the same percentage content in a mixture with viscous road petroleum bitumen, provide a lower cracking temperature. For the case of using a radial grade, this indicator is noticeably higher. Traditional bitumen has the lowest absolute value of fragility. This is in good agreement with the theory and practice of road construction (Nebratenko et al, 2022).

Conclusion

The practice of applying the ABCD method in Russian road science and practice does not yet have that broad level of application, which is inherent in the idea of the ABCD device.

And even the seemingly excessive duration of tests (about 4-5 hours), due, as noted earlier, to the reasonable requirements of the national standard GOST R 58400.11-2019, cannot prevent the expansion of its application for direct assessment of one of the most important performance indicators of polymer-bitumen binders - cracking temperature, because if the track or wear in the upper layers are formed gradually over a long period of time, the cracking during cooling develops spontaneously and the growth of the crack opening width increases even more when the temperature of the surface layer of the pavement passes through the zero mark, which in winter conditions in Russia happens with notable regularity.

The conducted studies have shown the practicality of using the ABCD method even in the case of traditional technologies since it gives reliable data on frost resistance and working capacity of binders and, consequently, of coatings based on them, in severe natural and climatic conditions of Russia. A simple hardware design, high-quality domestic software and the safety of the testing process provide this method of assessing the properties of bitumen binders with excellent prospects of development in the near future.

References

Flory, P.J. 1985. Network topology and the theory of rubber elasticity. *British Polymer Journal*, 17(2), pp.96-102. Available at: https://doi.org/10.1002/pi.4980170202.

Gokhman, L.M. 1977. Etude des propriétés rhéologiques des types structuraux de bitume sous déformation statique ou dynamique. In: *Bitumes et enrobes bitumineux: Bull liaison lab ponts chauss*, SPEC V, pp.59-67 [online]. Available at: https://trid.trb.org/view/1058887 [Accessed: 10 April 2023]. ISSN: 0458-5860.

Hesp, S.A.M. 2004. An Improved Low-Temperature Asphalt Binder Specification Method. In*: Development of a Fracture Mechanics-Based Asphalt Binder Test Method for Low Temperature Performance Prediction: Final Report for Highway IDEA Project 84*. Washington, D.C: Transportation Research Board of the National Academies [online]. Available at: https://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/highway/nchrp84_final_report.pdf [Accessed: 10 April 2023].

Kim, S.-S. 2005. Direct Measurement of Asphalt Binder Thermal Cracking. *Journal of Materials in Civil Engineering*, 17(6), pp.632-639. Available at: https://doi.org/10.1061/(ASCE)0899-1561(2005)17:6(632).

Kim, S.-S. 2007. *Development of an Asphalt Binder Cracking Device: Final Report for Highway IDEA Project 99*. Washington, D.C: Transportation Research Board of the National Academies [online]. Available at: https://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/highway/NCHRP99Final_Report.pdf [Accessed: 10 April 2023].

Mieczkowski, P., Budziński, B., Słowik, M., Kempa, J. & Sorociak, W. 2021. Experimental Study of Tensile Properties of Styrene-Butadiene-Styrene Modified Asphalt Binders. *Materials,* 14(7), art.number: 1734. Available at: https://doi.org/10.3390/ma14071734.

Nazzal, M.D., Kim, S.-S. & Abbas, A.R. 2014. Evaluation of Winter Pothole Patching Methods. *Rosap* [online]. Available at: https://rosap.ntl.bts.gov/view/dot/27019 [Accessed: 10 April 2023].

Nebratenko, D.Yu. & Nikolaevsky, V.E. 2023*. Metod opredelenija temperatury rastreskivanija bitumnyh vjazhushhih (ABCD): Metodicheskie rekomendacii k laboratornym rabotam.* Moscow: Russian University of Transport (MIIT), in Russian. (In the original: Небратенко, Д.Ю. и Николаевский, В.Е. 2023. *Метод определения температуры растрескивания битумных вяжущих (ABCD): Методические рекомендации к лабораторным работам*. Москва: РУТ (МИИТ).)

Nebratenko, D.Yu. 2022. ABCD – a method for assessing the low-temperature behavior of road binders. *Scientific Journal "Engineering and Construction Bulletin of the Caspian Region"*, 1(39), pp.37-41 [online]. Available at: https://xn--80aai1dk.xn--p1ai/journal/wp-content/uploads/2022/03/isvp_1_39_2022_37-41.pdf (in Russian) [Accessed: 10 April 2023].

Nebratenko, D.Yu., Boksha, M.Yu. & Isakov, A.M. 2022. Influence of SBS polymers of various structure on the properties of semi-blown bitumen binders. *Roads and Bridges - Drogi i Mosty*, 21(1), pp.5-17. Available at: https://doi.org/10.7409/rabdim.022.001.

Petersen, J.C., Robertson, R.E., Branthaver, J.F., Harnsberger, P.M., Duvall, J.J., Kim, S.-S, Anderson, D.A., Christiansen, D. & Bahia, H. 1994. *Binder characterization and evaluation. Volume 1.* Washington, D.C: Strategic Highway Research Program National Research Council [online]. Available at: https://onlinepubs.trb.org/Onlinepubs/shrp/SHRP-A-367.pdf [Accessed: 10 April 2023]. ISBN: 0-309-05809-0.

Plewa, A. 2019 Asphalt mixtures with binders fluidized by addition of vegetable origin oil for applications as flexible anti-crack layers. *Roads and Bridges - Drogi i Mosty*, 18(3), pp.181-192. Available at: https://doi.org/10.7409/rabdim.019.012.

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