Rheology properties of bitumen binders with various fillers

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Abstract:

Introduction: The resistance of road surfaces to the formation of a longitudinal wear mark from passing vehicles at the present stage is one of the most pressing problems in the field of asphalt concrete coatings. Therefore, the search for a solution to this problem constantly continues, including studying the behavior of various components of asphalt concrete mixtures when they are loaded.

Methods: The studies were carried out under static load in three temperature modes: 25°C, 40°C and 50°C, as well as using the standard DSR (dynamic shear rheometer) method at temperatures above 70°C. Two types of bitumen were used as binders: semi-blown petroleum road bitumen BND 100/130 and polymer bitumen binder PmB 90. Various fine fillers were introduced into their composition: marble dust, rubber crumbs and modified powder obtained by simultaneous grinding of marble with polyethylene.

Results: It was found that a fine filler has a stronger effect on creep than a change in the grade of asphalt concrete binder. The lowest creep and the greatest shear resistance in the entire temperature range of measurements were shown by an asphalt binder based on a powder obtained by joint grinding of marble and polyethylene.

Conclusions: The effect of a fine filler on the creep of a bitumen binder may exceed the effect associated with a change in the type of bitumen binder. It is obvious that it is the fine filler that has a greater effect on the stability of asphalt concrete to the formation of ruts than conventional semi-blown bitumen binders.

Keywords: rheology properties, asphalt-concrete, bitumen binders, asphalt binder, fillers, mineral powder, rutting, shear resistance, creep of an asphalt binder.

Introduction

The rutting resistance of the pavement surface is one of the most pressing problems in the field of asphalt concrete road construction. The annual increase in speed, traffic intensity and weight of vehicles (Olsson et al, 2019; Hou et al, 2015) indicates the increasing relevance of this problem in the future. Therefore, the search for a solution to this problem continues. To date, numerous studies have identified various factors influencing the formation of rutting in asphalt concrete pavements (Lira et al, 2019; Ai et al, 2017; Bodin, 2017; Ma et al, 2018). These include the influence of bitumen viscosity: hard grades of bitumen have a lower penetration degree and improve the resistance, whereas liquid grades worsen it (Alekseenko et al, 2019). However, other less important factors are suggested to affect rutting resistance. They may be roughly divided into two classes:

- structural factors, which include: grain size distribution and mixture homogeneity of mineral fillers, the maximum size and shape of crushed rock, and the porosity of a mineral aggregate (Akisetty et al, 2009; Qian et al, 2020);
- rheological properties of the binder: asphalt binder grade, the behavior of binder properties in the reaction with a finedispersed filler (mineral powder), the asphalt binder/mineral powder ratio, and the concentration of a binder in asphalt concrete (Ibrahim, 2019; Arun Kumar & Satyanarayana, 2015; Okhotnikova et al, 2019; Abdulmajeed & Muniandy, 2017).

As noted earlier, the viscosity of bitumen depending on the asphalt binder type has a considerable influence on the rutting resistance of asphalt concrete. The question arises: what other factors besides the bitumen grade might be relevant to the viscosity of bitumen? In our opinion, one of the most important factors is the type and amount of fine-dispersed filler. In most asphalt concrete compositions, this role is played by mineral marble dust. In asphalt concrete, approximately 90% of the total area occupied by mineral particles is the area of the mineral powder surface.

Selective adsorption of bitumen components onto the surface of particles or even inside them in modified powders of fine-dispersive fillers may considerably change the viscosity of the bitumen mixture if compared with the reference material. Therefore, the research into a bitumen composite with a fine-dispersed filler will make an important contribution to the field of asphalt binders. Therefore, it seems necessary to study the mixture of bitumen and fine-dispersive filler.

Purpose and problem statement

This study examines changes on the rheological properties of asphalt binders when mixed with a variety of fine-dispersed fillers. The properties of this composite differ considerably from the reference binder, so the term “an asphalt binder” is used throughout this paper as suggested in scientific literature. It is the asphalt binder that bonds coarse particles of asphalt concrete, and its properties are important for the rutting resistance of an asphalt concrete pavement, but only in that part that depends on the asphalt binder. Other structural factors influencing rutting resistance are beyond the scope of this study.

To assess the shear resistance and tensile strength of asphalt concrete, it is necessary to know the rheological properties of the asphalt binder in the contact zone of two mineral filler particles. At the same time, the speed of force application in real conditions of interaction of a car wheel with an asphalt concrete surface can vary greatly. Under rapidly changing loads on an asphalt concrete pavement, the main rheological property is the complex dynamic shear modulus (G*) which is stated by the equation:

$$G^{*}=G'+i^{*}G''= G^{*}\cos(\delta)+i^{*} G^{*}\sin(\delta) \quad (1)$$

where G’ is the storage shear modulus, G’’ is the loss shear modulus, δ is the phase angle, (in radians), defining the delay between sinusoidal deformation and sinusoidal stress during tests with controlled deformation. The value $G/\sin(\delta)$ is called resistance to shear deformation and it determines the contribution of bitumen to the shear resistance of asphalt concrete. For rapidly changing forces, there is a standard method AASHTO T315-10 "Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)" which allows to measure the shear stress of not only bitumen, but also asphalt binders.

Under slowly changing loads, for example, stopping a car, the creep stiffness of asphalt concrete will make a large contribution to the deformation.

The term “creep” refers to the deformation changing over time at a constant pressure. At the same time, the creep of asphalt concrete, if the fracture and rubbing of crushed mineral filler are ignored, is related to the deformation of the asphalt binder ΔX(t); its dependence upon the applied force P(t) and the impact time is stated in the equation:

$$\Delta X(t) = P(t)/k + fa(t) \quad (2)$$

where P(t) – the stress caused by external forces, k – the hardness of the asphalt binder, t – the time, and fa(t) – the function of the asphalt binder type and temperature. The constant k and the function fa(t) may be estimated either experimentally or by a computer-assisted experiment when fracturing asphalt concrete samples (Alekseenko et al, 2019). The creep measurements were carried out on a Kinexus DSR device using a special technique described below.

This study seeks to examine the creep and shear resistance of the asphalt binder. These experiments are far less difficult (cost-demanding) than measuring the creep (rutting) of asphalt concrete. In addition, the results obtained may be used in the future for the computer-assisted modeling of any physical and mechanical parameters of asphalt concrete.

Objects and materials for research

The study was carried out using two typical asphalt binders: petroleum road semi-blown bitumen grade BND 100/130 (BND) and polymer- modified bitumen grade PmB 90 (PmB). The three filler grades were used: a standard mineral powder from marble flour (MM), crumb rubber of automobile tires (RC), and a powder produced of marble dust and modified by polymers, which was a joint grinding of marble and polyethylene (MP).

These fillers were selected for some reasons:

- a standard powder from marble flour represents an etalon of an asphalt binder,

- crumb rubber is associated with an urgent problem of recycling waste tires; moreover, there is a vast body of literature on bitumen and rubber binders (Akisetty et al, 2009; Qian et al, 2020);

- a powder modified by polymers may resolve a problem of polymer recycling (Ibrahim, 2019; Arun Kumar & Satyanarayana, 2015; Okhotnikova et al, 2019), wherein the rutting resistance of asphalt concrete might be improved dramatically if the polymer and the powder modification method are selected appropriately.

Mineral powder from marble dust satisfied the Russian State Standard (GOST) 32761-2014, and the crumb rubber of waste tires (100%) was sieved (1 mm). The modified powder was a product of intergrinding marble powder with 10% (to the mass of mineral powder from marble) granulated high-density polyethylene. It took 4 hours to grind materials in a laboratory ball mill.

All samples of the asphalt binders for the creep research were prepared by heating and mix-ing bitumen binder and powder for 2 hours at a temperature of 175°C. The amount of filler in the bitumen binders was as follows: marble dust and bitumen binders were taken 1:1, 15% crumb rubber was added to BND and 10% to PmB, and modified powder and bitumen binders were in a ratio of 1:1. In this way, 8 samples of asphalt binders were obtained to study creep (Table 1).

Table 1 – Characteristics of the asphalt binder samples for creep research

№	The composition of the asphalt binder		Short name of the binder
	Bitumen type	Fillers (Mineral powder)	
1	BND 100/130	no filler	BND
2	PmB 90	no filler	PmB
3	BND 100/130	mineral powder from marble flour (MM)	BND/MM
4	PmB 90	mineral powder from marble flour (MM)	PmB/MM
5	BND 100/130	15% crumb rubber of automobile tires (RC)	BND/15RC
6	PmB 90	10% crumb rubber of automobile tires (RC)	PmB/10RC
7	BND 100/130	powder produced of marble dust and modified by polymers (MP)	BND/MP
8	PmB 90	powder produced of marble dust and modified by polymers (MP)	PmB/MP

Table 2 – Characteristics of the asphalt binder samples for the study of shear stability

№	The composition of the asphalt binder		Short name of the binder
	Bitumen type	Fillers (Mineral powder)	
1	BND 100/130	no filler	BND
2	PmB 90	no filler	PmB
3	BND 100/130	100% mineral powder from marble flour (MM)	BND/100MM
4	PmB 90	100% mineral powder from marble flour (MM)	PmB/100MM
5	BND 100/130	90% mineral powder from marble flour (MM) + 10% rubber crumb from car tires (RK)	BND/90MM/10RC
6	BND 100/130	90% mineral powder from marble flour (MM) + 10% polymer modified powder from marble flour (MP)	BND/90MM/10MP
7	PmB 90	90% mineral powder from marble flour (MM) + 10% polymer modified powder from marble flour (MP)	PmB/90MM/10MP

The filler amount in bitumen binders during shear resistance tests was as follows: the powder was mixed with the bitumen binders in a ratio of 1:1, while the powder consisted of 90% marble powder and 10% modifier by weight. Such a small amount of modifier was caused by the fact that dynamic measurements are more sensitive to changes in viscosity than creep measurements. Thus, 7 samples of asphalt binders were obtained for creep testing (Table 2).

Method for measuring shear resistance and creep research

The asphalt binder creep measurement was carried out using the standard procedure described below on a DSR instrument which is used to measure the creep of asphalt binders. The measurements were carried out at temperatures of 25 °C, 40 °C and 50°C for eight types of asphalt binders, the characteristics of which are given in Table 1. This temperature range is typical for real asphalt concrete pavements. In addition, at lower temperatures, the creep of the asphalt binder is too small; at higher temperatures, the difference in the creep of various asphalt binders is increasingly leveled out. The measurement of the complex shear modulus of the asphalt binder was carried out according to the standard methods when determining the grade of bitumen according to PG (Performance Grade). The temperature range of the measurement in this case corresponded to the expected softening temperature of the asphalt binder.

Measuring creep and shear resistance by Kinexus DSR

The measurements were carried out for a spindle of 25 mm, a space of 1 mm, and a shear force of 50 kPa. Once the temperature was stabilized, a shear force was applied for 60 seconds (20 seconds at high temperatures and low shear resistance of the asphalt binder), and the curve presenting the rotational displacement of a spindle vs. time was analyzed. It is apparent that the deformation is linear for all types of asphalt binders at all temperatures under consideration, so the creep function may be stated in the equation:

$$fa(t) = \alpha \cdot t \quad (3)$$

where the constant α is related to the asphalt binder type and temperature. In some tests, the creep demonstrated non-linear behavior over the first seconds, so Table 3 below provides the data for the linear section of the creep. To compare, the creep of the bitumen binders without fillers was measured at low temperatures. The measurement failed at a temperature of 50 °C and a shear force of 50 kPa because bitumen binders without fillers have low shear resistance.

Results

The speed of the spindle phase angle change characterizes the creep of the asphalt binder at a constant shear force. The results of its measurement are presented in Table 3.

Table 3 – The rate of the change of the spindle rotation angle (rad/s) at different temperatures

№	Short name of the binder	Temperature		
		25,°C	40,°C	50,°C
1	BND	0.325	605	*
2	PmB	0.030	2.400	*
3	BND/MM	0.028	3.333	1200
4	PmB /MM	0.013	0.188	890
5	BND/15RC	0.011	0.183	667
6	PmB/10RC	0.003	0.140	625
7	BND /MP	0.00014	0.0035	0.057
8	PmB/MP	0.00002	0.0015	0.011

*- no data, because bitumen binders without fillers have low shear resistance

Thus, any fine-dispersed filler decreases dramatically the creep of the bitumen binder. Furthermore, a PmB-based asphalt binder has lower creep than a BND-based material; however, a modified mineral powder provides the best creep reduction effect. Rubber crumb at temperatures of 25 °C and 40 °C has a stronger effect on the bitumen binder than marble dust, while at 50 °C it is vice versa.

The results of testing the shear resistance of asphalt binders (the parameters of the dynamic modulus of elasticity of asphalt binders), carried out according to the standard method, which is performed when determining the grade of binder according to PG (Performance Grade), are shown in Figure 1.

From Figure 1 it is obvious that, as in the experiments measuring creep, fine powders noticeably change the viscosity of the binder. The strongest effect on the change in viscosity is provided by mineral powder obtained by jointly grinding the mineral part and polyethylene.

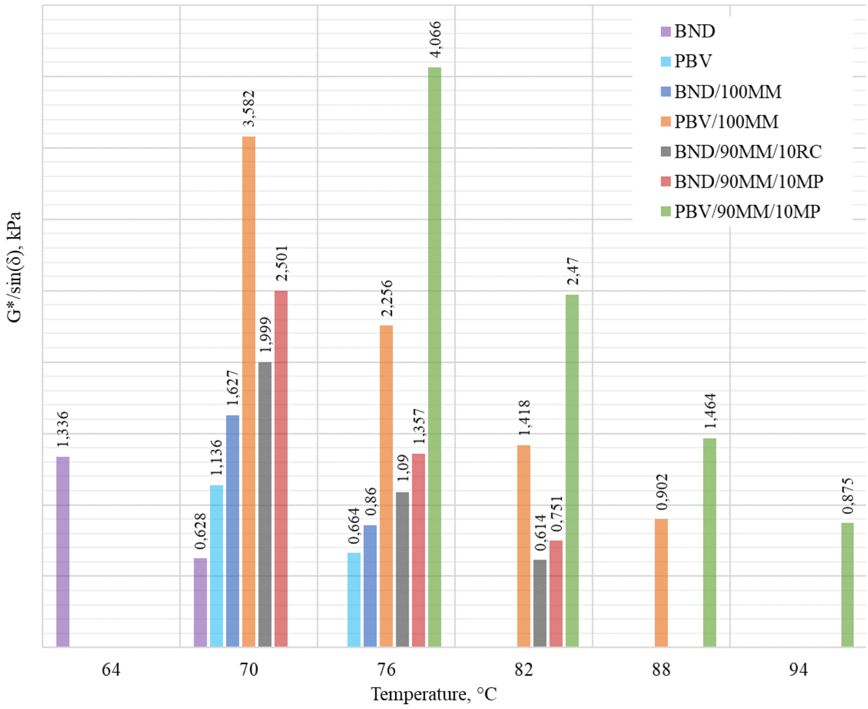

Figure 1 – Parameters of the dynamic modulus of elasticity of asphalt binders

Conclusion

The study showed that fine-dispersed fillers have a strong influence on the creep and shear stability of bitumen binders. This influence is far more significant than the behavior of bitumen if SBS grades are dissolved. Moreover, the influence of fine-dispersed fillers is equally pronounced in bitumen and polymer bitumen binders. The least creep and the highest shear resistance over the entire temperature range were shown in the asphalt binder produced by joint intergrinding marble and polyethylene.

The technology for improving the shear resistance of asphalt concrete through the use of modified mineral powders has a significant advantage compared to the technology for modifying bitumen by dissolving polymers. When using modified mineral powders, there is no problem of storage, change in properties and delamination of the binder. When modifying bitumen with various polymer and inorganic modifiers, the problem of binder degradation as a result of delamination, oxidation and other factors is always relevant.

It should also be noted that the estimation of the rheological parameters of asphalt binders is the quickest and most reliable method to assess the strength and shear resistance of asphalt concrete.

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Propiedades reológicas de aglutinantes bituminosos con diversos rellenos

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CAMPO: tecnología química, industria química, construcción
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La resistencia de las superficies de las carreteras a la formación de marcas de desgaste longitudinal por el paso de vehículos es en la actualidad uno de los problemas más apremiantes en el campo de los revestimientos de hormigón asfáltico. Por lo tanto, la búsqueda de una solución a este problema continúa constantemente, incluido el estudio del comportamiento de los diversos componentes de las mezclas de hormigón asfáltico cuando se cargan.

Métodos: Los estudios se llevaron a cabo bajo carga estática en tres modos de temperatura: 25°C, 40°C y 50°C, así como utilizando el método estándar DSR (reómetro de corte dinámico) a temperaturas superiores a 70°C. Como aglutinantes se utilizaron dos tipos de betún: betún de petróleo semi - soplado para carreteras BND 100/130 y aglutinante de betún polimérico PmB 90. En su composición se introdujeron diversos rellenos finos: polvo de mármol, virutas de caucho y polvo modificado obtenido mediante trituración simultánea de mármol con polietileno.

Resultados: Se encontró que un relleno fino tiene un efecto más fuerte sobre la fluencia que un cambio en el grado del ligante de concreto asfáltico. La menor fluencia y la mayor resistencia al corte en todo el rango de temperaturas de medición las mostró un aglutinante asfáltico a base de un polvo obtenido mediante la trituración conjunta de mármol y polietileno.

Conclusión: El efecto de un relleno fino sobre la fluencia de un ligante bituminoso puede exceder el efecto asociado con un cambio en el tipo de ligante bituminoso. Es obvio que es el relleno fino el que tiene un mayor efecto sobre la estabilidad del hormigón asfáltico ante la formación de surcos que los aglutinantes bituminosos semi - soplados convencionales.

Palabras claves: propiedades reológicas, asfalto-concreto, ligantes bituminosos, ligante asfáltico, rellenos, polvo mineral, ahuellamientos, resistencia al corte, fluencia de un ligante asfáltico.

Реологические характеристики битумных вяжущих с различными наполнителями

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РУБРИКА ГРНТИ: 67.15.00 Технология производства строительных материалов и изделий,
67.15.49 Производство материалов на основе органических вяжущих. Производство асфальтобетона
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение: Устойчивость дорожных покрытий к образованию колеи от проезжающих транспортных средств на современном этапе является одной из наиболее актуальных проблем в области асфальтобетонных покрытий. Увеличение скоростей движения автотранспорта и увеличение нагрузки на ось автомобиля делает эту задачу из года в год все более важной. Поэтому поиск решения этой проблемы постоянно продолжается, в том числе путем изучения поведения различных компонентов асфальтобетонных смесей под нагрузкой.

Методы: Данное исследование отражает экспериментальные данные по измерению реологических свойств битумных вяжущих *при различных скоростях деформации. Исследования проводились при статической нагрузке в трех температурных режимах: 25°C, 40°C и 50°C, а также с использованием стандартного метода DSR (динамический реометр сдвига) при температурах выше 70°C. В качестве двухкомпонентных вяжущих были использованы два вида битума: окисленный нефтяной дорожный битум БНД 100/130 и полимерно-битумное вяжущее ПБВ 90. В их состав были введены различные мелкодисперсные наполнители: мраморная пыль, резиновая крошка и модифицированный порошок, полученный путем взаимного измельчения мрамора с полиэтиленом.*

Результаты: Показано, что мелкий наполнитель оказывает более сильное влияние на ползучесть асфальтобетонного вяжущего, чем изменение марки асфальтобетонного вяжущего. Наименьшую ползучесть и наибольшую устойчивость к сдвигу во всем диапазоне температур измерений продемонстрировало асфальтовое вяжущее на основе порошка, полученного совместным измельчением мрамора и полиэтилена.

Выводы: Показано, что влияние мелкодисперсного наполнителя на ползучесть битумного вяжущего может превышать эффект, связанный с изменением типа битумного вяжущего. Этот результат указывает на то, что именно мелкодисперсный наполнитель оказывает большее влияние на устойчивость асфальтобетона к образованию колеи, чем обычные битумные вяжущие.

Ключевые слова: реологические свойства, асфальтобетон, битумные вяжущие, асфальтовяжущее, наполнители, минеральный порошок, колееобразование, сопротивление сдвигу, ползучесть асфальтовяжущего.

Реолошке карактеристике битуменских везива са различитим филерима

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ОБЛАСТ: хемијске технологије, хемијска индустрија, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод: Један од горућих проблема у области превлака од асфалтног бетона јесте отпорност површина путева на формирање уздужних трагова хабања од точкова возила. Решење се још увек тражи, а обухвата и проучавање понашања различитих компоненти мешавина асфалтног бетона при оптерећењу.

Методе: Испитивања су вршена под статичким оптерећењем у три температурна режима (25°C, 40°C и 50°C), као и помоћу стандардне методе ДСР (реометар за динамичко смицање) на температурама изнад 70°C. Две врсте битумена коришћене су као везива: битумен за путеве од ваздухом продуване нафте БНД 100/300 и полимер модификовани битумен ПмБ 90. У мешавину су уведене различите ситне фракције – филери: мермерни прах, мрвице гуме и модификовани прах добијен истовременим млевењем мермера и полиетилена.

Резултати: Утврђено је да ситна фракција има већи утицај на течење од промене степена везива асфалтног бетона. Показало се да најнижу вредност течења и највећу отпорност на смицање у свим испитиваним температурним режимима има асфалтно везиво на бази праха добијеног заједничким млевењем мермера и полиетилена.

Закључак: Утицај ситне фракције филера на течење битуменског везива може да буде значајнији од утицаја промене врсте битуменског везива. Очигледно је да ситна фракција – филер има већи ефекат на стабилност асфалтног бетона при формирању колотрага од конвенционалних битуменских везива добијених удувавањем ваздуха.

Кључне речи: реолошка својства, асфалтни бетон, битуменска везива, асфалтно везиво, филери, минерални прах, формирање колотрага, отпорност на смицање, течење асфалтног везива.

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