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LABORATORY STUDIES TO REDUCE THE TECHNOLOGICAL AGING OF BITUMEN

Abstract

Introduction. Long performance of pavements is ensured by preserving the stability of their basic physical and mechanical characteristics under various operating loads and weather and climatic conditions. One of the main factors contributing to such stability is aging resistance of bitumen.

Problem statement. Aging bitumen process is a combination of irreversible changes in the structure and physical and technical characteristics of bitumen that occur when using them exposed to external factors. The most rapid aging of bitumen occurs in the thin films at the preparation of asphalt mixes.

Also, during the operation of asphalt pavements, constant changes in the properties of bitumen leading to the deterioration of its quality and the destruction of asphalt are continuously occur.

Purpose. Development of technologies aimed at reducing the aging of bitumen during technological processing which will improve the quality of bitumen and asphalt concrete and extend the service life of road pavements.

Results. In this paper, measures and technologies for improving the stability of bitumen and asphalt to technological aging are defined.

Introduction of surfactants in bitumen virtually does not affect its physical and technical properties. However, they enable increasing stability of oxidized bitumen to aging by changing the structure formation processes in bitumen and adsorption of surfactants on asphaltenes.

Compounding of oxidized bitumen with residual bitumen leads to increase in its residual penetration and reduction in the aging indices.

Use of energy-saving additives allows reducing the temperature of preparation and compaction of asphalt mixes, thereby promoting reducing thermo-oxidative aging of bitumen and thus increasing its durability.

Conclusions. Developed technologies for increasing the stability of bitumen and asphalt concrete to aging will extend the service life of road pavements.

Key words: asphalt concrete, bitumen, energy-saving additive, compounding, aging of bitumen,surfactants.

Scope

Long performance of flexible pavements is ensured by preserving the stability of their basic physical and mechanical characteristics under various operating loads and weather and climatic conditions. One of the main factors contributing to such stability is aging resistance of bitumen.

During the operation of asphalt concrete pavements constant changes in the properties of bitumen leading to the deterioration of its quality and the destruction of asphalt are continuously occurred. However, the aging of bitumen occurs not only when it is a part of asphalt pavement. Irreversible changes in the properties of bitumen are observed at the stage of its preparation at asphalt plant which may result in the premature destruction of asphalt pavements. It has repeatedly been noted in the works of Kolbanovska [1], Rudenska [2] and other.

The aim of this work was to improve the stability of oxidized bitumen to thermo-oxidative aging.

To simulate thermo-oxidative aging, the RTFOT method was used (according to EN 12607-1 [3]) which simulates the processes of preparation, storage and laying hot asphalt mixes and takes into account constant updating of bitumen surfaces while stirring it with hot mineral materials. Aging of bitumen by this method is carried out at continuous air intake and thus thermo-oxidative aging takes place.

Resistance of bitumen to aging is assessed by the indicators that to the utmost characterize the change of bitumen consistency, namely by residual penetration (ratio of bitumen penetration after heating to the initial bitumen penetration) and aging index (ratio of dynamic viscosity of bitumen after heating to the dynamic viscosity of initial bitumen).

Research of the stability of oxidized bitumen to thermo-oxidative aging

For the research purposes, bitumen of BND 60/90 (BND is a brand according to DSTU 4044 [4]) and BND 90/130 brand produced by PJSC «Ukrtatnafta» were taken. The investigated bitumen show typical characteristics of oxidized bitumen and by the values of its physical and technical properties meet the requirements of DSTU 4044 [4] (Table 1).

Heating of bitumen by RTFOT method leads to changes in its properties. Values of residual penetration of bitumen are within the range from 60 % to 62 %. That is, regardless bitumen brand, its resistance to aging is almost the same in terms of residual penetration. At the same time, aging index values indicate that more viscous bitumen is less resistant to aging. At almost the same residual penetration, aging index of bitumen of brand BND 60/90 is in 1,15 times higher.

Given significant changes in the properties of bitumen at heating, there is a need to improve its resistance to high processing temperatures.

Table 1

Test results of bitumen investigation

Indicators	Test results of bitumen investigation			Test methods
	brand BND 60/90		brand BND 90/130	
Depth of needle penetration at temperature 25 ºС, m×10^{-4}	67	76	110	EN 1426[5]
Softening point (by ring and ball), ºС	49,7	48,6	45,1	EN 1427[6]
Brittleness temperature, ºС	-24	-24	-25	EN 12593[7]
Ductility at temperature 25 ºС, m×10^{-2}	68	70	80	ASTM D113[8]
Ductility at temperature 0 ºС, m×10^{-2}	3,0	3,2	4,0	ASTM D113[8]
Dynamic viscosity at temperature 60 ºС, Pa·s	390	326	198	EN 13302 [9]
Residual penetration, %	60	62	62	EN 12607-1 [3]
Aging index	3,12	3,03	2,65	EN 12607-1 [3]

To increase the resistance of bitumen and, therefore, of asphalt to high processing temperatures is possible by the use of surfactants, improving the structure of oxidized bitumen by their compounding with residual bitumen, as well as by reducing the processing temperature of production and laying of asphalt mixes through the use of special energy-saving additives.

The use of surfactants

Aging of bitumen under the influence of thermo-oxidative factors includes the processes of emergence, development and destruction of a rigid spatial structure of asphaltenes. We can therefore assume that any substances that prevent the formation of spatial structures contribute to aging slowing even without changing in the oxidation process associated with the increase in the number of asphaltenes, as is in the case with the introduction of bitumen inhibitors.

Introduction of cationic surfactants in bitumen that are adsorbed on the asphaltenes and block the points of their possible contacts is connected with the stabilizing effect and leads to the transformation of coagulation spatial structure in a highly concentrated unstructured suspension of asphaltenes [1].

A study was conducted of the impact of cationic surfactant, a natural product of a synthesis of fatty acids, low molecular amines and organic solvent to improve the stability of bitumen to thermo-oxidative aging.

Bitumen modification by surfactant was performed at a temperature (145 - 150) °C for 60 min. The content of surfactant in bitumen was 0,5 %, 0,75 % and 1,0 %.

The test results show that at the introduction of surfactant negligible plasticizing of bitumen occurs (Table 2). Its penetration increases, its softening point reduces. Dynamic viscosity of bitumen when introducing surfactant is increasing slightly which indirectly indicates its structuring effect.

Table 2

Influence of surfactants on bitumen properties

Indicators	Test results of bitumen investigation of BND 60/90 grade			
	initial	modified by surfactant, %		
		0,5	0,75	1,0
Depth of needle penetration at temperature 25 ºC, m×10^{-4}	67	68	70	72
Softening point (by ring and ball), ºC	49,7	49,2	48,8	48,2
Dynamic viscosity at temperature 60 ºC, Pa·s	390	420	405	380
Residual penetration, %	60	72	74	75
Aging index	3,12	2,60	2,52	2,47

Bitumen modified by surfactants is more resistant to aging. The residual bitumen penetration with 0,5 % of surfactant is by 20 % larger than the residual penetration of initial bitumen.

With increasing content of surfactants residual penetration of bitumen continues to grow and with its content at 0,75 % and 1,0 % it is by 23 % and 25 % respectively higher than the residual penetration of initial bitumen. Similar results were obtained when determining aging index.

In addition it should be noted that the penetration of initial bitumen after aging (i.e. penetration of bitumen contained in the asphalt pavement) is 40 m×10^{-4}, and of bitumen with 1,0 % of surfactant is 54 m×10^{-4}. This means that the bitumen with 1,0 % of surfactant after aging has in 1,35 times higher penetration than the initial aged bitumen which must surely increase the durability of asphalt pavement.

Compounding of bitumen

The tendency of bitumen to aging depends on many factors including bitumen component composition and nature of raw materials, technology of its generation, etc. It is believed that oxidized bitumen which is the most common in the road construction of Ukraine is intermediate between the bitumen obtained from cracking residues most prone to rapid aging, and the residual bitumen that is the most resistant to aging. However, there is evidence that oxidized bitumen from road tar based on certain oils has higher resistance to aging than the residual bitumen, repeatedly confirming the statement that aging bitumen is a complex phenomenon and it depends on many factors.

In recent years, a number of studies on the improvement of bitumen resistance to aging have been fulfilled. In particular, Israilova [10] proposed the concept of increasing the resistance of thermo-oxidized bitumen to aging which consists in reducing the number of structure-forming components - asphaltenes which are characterized by high concentrations of free radicals that trigger aging of bitumen at storage and preparation of bitumen mineral mixes by compounding the latest with the leavings of crude and vacuum distillation of crude oil. In their works Nat Chan Tian [11] propose to increase the resistance of bitumen to thermo-oxidative aging by optimizing the type chemical composition of raw materials for bitumen.

It is likely to increase the resistance of oxidized bitumen to high processing temperatures and operational factors by its compounding with residual bitumen.

Compounded bitumen obtained by the combination of oxidized bitumen of BND 60/90 brand that meets the requirements of DSTU 4044 [4] with the residual bitumen of 100/150 brand that meets the requirements of EN 12591 [12]. Combination was performed at a temperature (160 - 165) °C for 2,0 hours.

The content of residual bitumen ranged from 10 % to 50 % by weight of compounded bitumen. Test results of initial and compounded bitumen are shown in Table 3.

Table 3

The results of determining the physical and technical properties of bitumen obtained by compounding of different types of bitumen

Indicators	Test results				
	oxidized bitumen of BND 60/90 brand	distillation bitumen of 100/150 brand	compounded bitumen based on oxidized bitumen of BND 60/90 brand containing distillation bitumen of 100/150 brand, %		
			10 %	30 %	50 %
Depth of needle penetration at temperature 25 ºC, m×10^{-4}	67	106	66	75	86
Softening point (by ring and ball), ºC	49,7	42,2	48,7	46,2	44,4
Dynamic viscosity at temperature 60 ºC, Pa·s	390	168	405	275	230
Residual penetration, %	60	65	73	71	67
Aging index	3,12	2,05	2,40	2,54	2,40

The residual penetration of oxidized bitumen at heating by the RTFOT method is 60 %. Adding to oxidized bitumen of 10 % of 100/150 brand bitumen increases the residual penetration to 73 % (Figure 1).

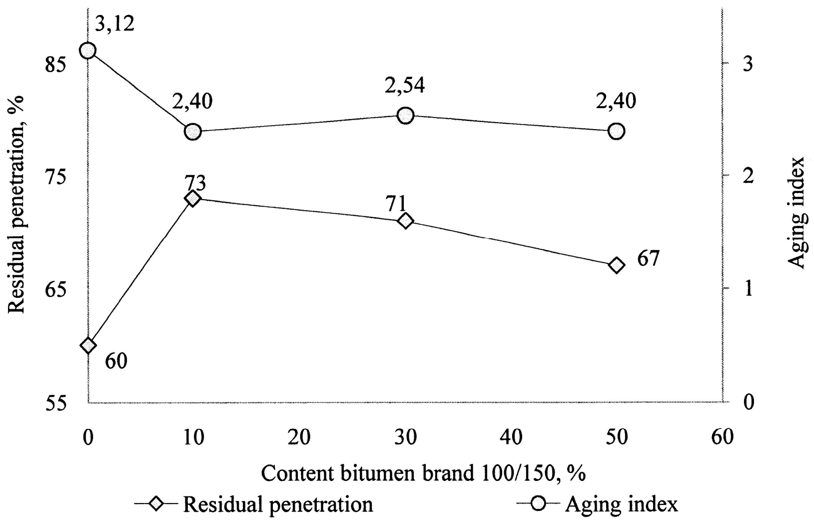

Figure 1 **–** Residual penetration of compounded bitumen depending on the content of distillation bitumen

Increase in the residual penetration at heating indicates that compounded bitumen compared with the oxidized one changes its consistency less and, therefore, is more resistant to aging.

Increase in the content of residual bitumen to 30 % and 50 % leads to the decrease in the index of residual penetration. However, residual penetration of compounded bitumen is still higher than of the oxidized bitumen. In this case, the reduction in the residual penetration is likely due to increased penetration of compounded bitumen, as it is widely accepted that less viscous bitumen is aging more intensely than the viscous one.

The value of aging index also indicates a higher resistance to aging of compounded bitumen compared to the oxidized one (Figure 1). Even with the introduction of 10 % of distillation bitumen of 100/150 brand, a significant decrease in the aging index from 3,12 to 2,40 is observed. By increasing the distillation bitumen content to 30 % and 50 % aging index is virtually unchanged, indicating increased resistance of compounded bitumen to aging even with the increase in its penetration (i.e. less viscous compounded bitumen change its properties at thermo-oxidative aging not more than viscous binders).

Thus, the test results show that compounded bitumen is more resistant to aging than oxidized bitumen. Even with the introduction of 10 % of residual bitumen to the oxidized bitumen, a significant increase in the durability of oxidized bitumen to aging is observed testifying to an increase in the durability of asphalt based on compounded bitumen.

Reducing processing temperatures of production and laying of asphalt mixes

Today in Ukraine, hot asphalt mixes are used almost exclusively for the arrangement of road pavements.

Hot asphalt mixes are produced using viscous bitumen at a temperature (140 - 170) °C. In this temperature range the viscosity of the bitumen is reduced to a level at which it easily envelops hot gravel; the mix is sufficiently workable that ensures its uniform mixing and subsequent transportation to the storage tank. The upper temperature limit for heating the binder and mineral material is limited due to the intense oxidative binder aging at processing temperatures of stirring the mix. Hot mix is placed and its compaction is started at temperatures (135 - 155) °C, and its rolling is completed at temperatures lower than 80 °C.

Heating the bitumen and its subsequent mixing with mineral material leads to increasing the viscosity of bitumen which in turn reduces the workability of asphalt mix. As you know, the quality of future pavement and conditions of works performance are largely determined by the workability of asphalt mix at laying and compaction. Durable pavement can be obtained only if the mix is quite easily placed with the layer of a given thickness, well leveled and compacted. This mix provides a flat, smooth and uniform surface.

The quality of mix placing is also affected by the temperature of the mix at placing. The higher the temperature of the mix - the lower is the viscosity of bitumen; the higher its flowability - the better is its workability.

For the production of quality asphalt mixes various technological solutions are used, as well as special additives that reduce the temperature of their preparation and placement, thereby reducing aging of bitumen.

The results of studies of the effect of temperature of bitumen heating by the RTFOT method (Figure 2) on change in its properties show that when the test temperature is reduced, bitumen less changes its properties. Residual penetration of initial bitumen at the test temperature reduction by 20 °C increases from 60 % to 67 % and by 40 °C - from 60 % to 80 %.

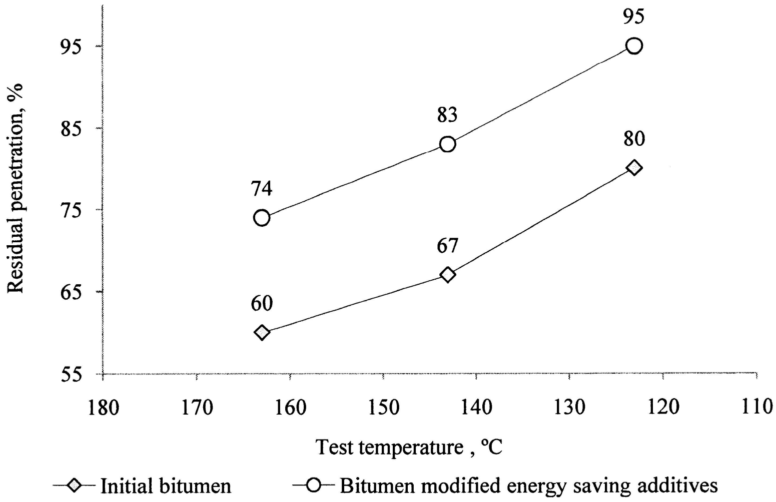

Figure 2 – Effect of temperature on residual penetration of bitumen

However, preparing asphalt mixes at low temperatures is only possible using special energy-saving additives. As seen in Figure 2, the introduction of energy-saving additives increases the residual penetration of bitumen from 60 % to 74 %, i.e. energy-saving additive increases the resistance of bitumen to aging. Lowering the test temperature by 20 °C and 40 °C increases the residual penetration to 83 % and 95 %, respectively. This indicates that in case of the preparation of asphalt mixes based on bitumen with energy-saving additive at low temperatures bitumen much less changes its properties, and thus extends the service life of asphalt pavements.

With the introduction of energy-saving additives, the possibility of lowering the temperature of preparation and placing of asphalt mixes is achieved by reducing the surface tension of bitumen or by reducing the viscosity of bitumen when it is heated above the melting point of waxes included in the additive.

Using rotational viscometer Brookfield, the temperature- viscous dependence of initial and modified bitumen was studied and temperature at which viscosity of bitumen reaches the value of 0,5 Pa·s (maximum viscosity at which high-quality mixing with binder mineral materials is provided). For the initial bitumen this temperature is 142 °C, and for the bitumen modified with 0,5 % of energy saving additives it is 143 °C. Thus, the results indicate that the adopted for research energy-saving additive allows reducing the temperature of preparation and laying of asphalt mixes by reducing the surface tension of bitumen.

The studies of asphalt mixes preparation temperature influence on the properties of asphalt have been conducted.

Preparation of asphalt mixes based on the initial bitumen and on the bitumen modified with energy-saving additive was carried out in compliance with the standard sequence of process operations according to DSTU B V.2.7-319 [13].

Temperatures of heating materials at the preparation of asphalt mixes at standard temperatures in the lab in compliance with DSTU B V.2.7-319 [13] and taking into account selected temperature conditions were as follows: for gravel, sand and filler – (170 - 175) °C, bitumen – (140 - 145) °C. The mix was compacted at a temperature (150 - 155) °C.

At lowering the temperature of asphalt mix preparation by 20 °C the temperatures of heating the materials were as follows: for gravel, sand and filler – (150 - 155) °C, for bitumen - (140 - 145) °C. The mix was compacted at a temperature (130 - 135) °C.

At lowering the temperature of asphalt mix preparation by 40 °C the temperatures of heating the materials were as follows: for gravel, sand and filler – (130 - 135) °C, for bitumen – (140 - 145) °C. The mix was compacted at a temperature (110 - 115) °C.

Test results of asphalt based on the initial bitumen and of asphalt based on the bitumen with energy-saving additive are shown in Table 4.

Table 4

Test results of asphalt prepared at various temperatures

Indicators	Processing temperatures		Test results of asphalt based on bitumen	
	mixing	compaction	BND 60/90	BND 60/90 + 0,5 % energy-saving additives
Average density, g/cm^3	170-175	150-155	2,366	2,379
	150-155	130-135	2,359	2,371
	130-135	110-115	2,349	2,362
Water saturation, %	170-175	150-155	1,9	1,6
	150-155	130-135	2,4	1,9
	130-135	110-115	3,1	2,3
Water resistance coefficient	170-175	150-155	0,95	1,00
	140-145	130-135	0,92	0,98
	120-125	110-115	0,88	0,96
Compressive strength, MPa, at temperature:				
0 °C	170-175	150-155	9,22	9,42
	140-145	130-135	8,68	8,97
	120-125	110-115	7,82	8,59
20 °C	170-175	150-155	4,62	4,69
	140-145	130-135	4,21	4,31
	120-125	110-115	3,94	4,06
50 °C	170-175	150-155	1,71	1,70
	140-145	130-135	1,48	1,61
	120-125	110-115	1,35	1,49

Test results show that the density of asphalt with energy-saving additive is higher than that of asphalt based on the initial bitumen. Average density of asphalt samples based on the initial bitumen, as well as of those based on the bitumen with energy-saving additive decreases in parallel with decreasing temperature of asphalt mixes preparation and compaction. At that, the nature of decreasing the average density of asphalt concrete samples is identical. However, due to higher average density of asphalt based on the bitumen with energy-saving additive prepared under standard temperature, average density of asphalt based on the same bitumen prepared under lowered by 40 °C temperature is practically the same as the average density of asphalt based on the initial bitumen and prepared at standard temperatures.

Along with increasing density, water saturation of asphalt decreases at its modification by energy-saving additives. As the temperature of preparation and compaction of asphalt mixes increases, the growth in the water saturation index for both asphalt compositions is observed. Thus, for asphalt with energy-saving additive water saturation growth is less intense than for asphalt based on the initial bitumen. It should also be noted that at reducing the temperature of asphalt mixes preparation based on the initial bitumen by 40 °C for the specified index asphalt does not meet the requirements of DSTU B V.2.7-119 [14].

The introduction of energy-saving additives in asphalt increases the water resistance coefficient from 0,95 to 1,00. Lowering the temperature of asphalt mixes preparation and compaction leads to the reduction in the water resistance coefficient. Decreasing water resistance of asphalt based on bitumen modified by energy-saving additive is less intense than of asphalt based on the initial bitumen. Asphalt based on the initial bitumen obtained at lowered by 40 °C temperature does not meet the requirements of DSTU B V.2.7-119 [14] in terms of water resistance coefficient.

With the introduction of energy-saving additives an increase in compression strength of asphalt has been observed at 20 °C and 0 °C and at 50 °C the strength is not changed. The decrease in the strength of asphalt at the temperature of asphalt mixes preparation and compaction takes place in all cases at temperature decreasing. For asphalt based on the initial bitumen the decrease in strength is higher than for asphalt based on the bitumen modified by energy-saving additive. Most significantly the strength of asphalt is reduced at lowering by 40 °C of the temperature of asphalt mixes preparation based on the initial bitumen.

Thus, it can be stated that the use of energy-saving additives allows reducing the processing temperatures of asphalt mixes preparation and compaction. Asphalt based on the bitumen modified by energy-saving additive prepared and compacted at lowered by 40 °C temperatures is almost identical to asphalt based on the unmodified bitumen and prepared under standard temperatures.

Conclusions

1. At thermo-oxidative aging of bitumen a change in its properties takes place. Its penetration is reduced and its dynamic viscosity is increased which adversely affects the durability of asphalt.
2. Modification of bitumen by surfactants virtually does not affect its physical and technical properties. However, surfactants have a significant impact on the stability of bitumen to thermo-oxidative aging.
3. Introduction of residual bitumen to the oxidized bitumen results in an increase in its residual penetration and reduction in aging index at heating in compliance with EN 12607-1, indicating a higher resistance to aging of compounded bitumen compared to the oxidized one, and therefore higher durability of asphalt based on compounded bitumen.
4. Use of energy-saving additives at the preparation of asphalt and polymer asphalt mixes allows reducing the temperature of its preparation and compaction by 40 °C. Asphalt with energy-saving additives prepared according to standard and lowered processing temperatures meets the requirements of DSTU B V.2.7-119.

5. Lowering the temperature of asphalt mixes preparation and compaction reduces the thermo-oxidative aging of bitumen and, consequently, increases the service life of asphalt pavements.

6. Besides, lowering the temperature of preparation and laying of asphalt mixes allows reducing energy resources consumption and improving environmental situation in the country.

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ЛАБОРАТОРНІ ДОСЛІДЖЕННЯ ЩОДО ЗМЕНШЕННЯ ТЕХНОЛОГІЧНОГО СТАРІННЯ БІТУМІВ

Анотація

Вступ. Довговічність дорожніх покриттів забезпечується збереженням стабільності їх основних фізико-механічних характеристик при різних робочих навантаженнях, погодних та кліматичних умовах. Одним з основних факторів, що сприяють такій стабільності, є стійкість бітуму до старіння.

Проблематика. Процес старіння бітумів – це сукупність незворотних змін структури та фізико-технічних характеристик бітумів, що відбуваються при їх використанні під дією зовнішніх факторів. Найбільш швидке старіння бітумів відбувається в тонких плівках при приготуванні асфальтобетонних сумішей. Головними чинниками старіння при цьому є кисень повітря і висока температура, які обумовлюють інтенсивні окиснювальні та термоокиснювальні процеси.

Також, постійні зміни властивостей бітуму відбуваються під час експлуатації асфальтобетонних покриттів, які призводять до погіршення його якості та руйнування асфальтобетону.

Мета. Розробка технологій, спрямованих на зменшення старіння бітумів при технологічній переробці, що дозволить підвищити якість бітумів і асфальтобетонів та подовжити строки служби дорожніх покриттів.

Результати. В роботі досліджено зміну властивостей бітумів при технологічному старінні. Встановлені заходи та технології підвищення стійкості бітумів до технологічного старіння.

Введення до складу бітуму поверхнево-активних речовин практично не впливає на їх фізико-технічні властивості. Однак вони дають можливість підвищити стійкість окислених бітумів до старіння шляхом зміни процесів структуроутворення в бітумі та адсорбції поверхнево-активних речовин на асфальтенах.

Компаундування окисленого бітуму з залишковим бітумом призводить до зростання його залишкової пенетрації та зниження індексів старіння.

Використання енергозберігаючих добавок дозволяє знизити температури приготування та ущільнення асфальтобетонних сумішей, що сприяє зменшенню термоокислювального старіння бітуму, а отже підвищенню його довговічності.

Висновки. Розроблені технології підвищення стійкості бітумів і асфальтобетонів до старіння дозволять подовжити строки служби дорожніх покриттів.

Ключові слова: асфальтобетон, бітум, енергозберігаюча добавка, компаундування, старіння бітуму, поверхнево-активна речовина.

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ЛАБОРАТОРНЫЕ ИССЛЕДОВАНИЯ ПО СНИЖЕНИЮ ТЕХНОЛОГИЧЕСКОГО СТАРЕНИЯ БИТУМОВ

Аннотация

Введение. Долговечность дорожных покрытий обеспечивается сохранением стабильности их основных физико-механических характеристик при различных рабочих нагрузках, погодных и климатических условиях. Одним из основных факторов, способствующих такой стабильности является устойчивость битума к старению.

Проблематика. Процесс старения битумов - это совокупность необратимых изменений структуры и физико-технических характеристик битумов, происходящих при их использовании под действием внешних факторов. Наиболее быстрое старение битумов происходит в тонких пленках при приготовлении асфальтобетонных смесей. Главными факторами старения при этом является кислород воздуха и высокая температура, обуславливающие интенсивные окислительные и термоокислительные процессы.

Также постоянные изменения свойств битума происходят во время эксплуатации асфальтобетонных покрытий, которые приводят к ухудшению его качества и разрушению асфальтобетона.

Цель. Разработка технологий, направленных на уменьшение старения битумов при технологической переработке, что позволит повысить качество битумов и асфальтобетонов и продлить сроки службы дорожных покрытий.

Результаты. В работе исследовано изменение свойств битумов при технологическом старении. Установлены меры и технологии повышения устойчивости битумов к технологическому старению.

Введение в состав битума поверхностно-активных веществ практически не влияет на их физико-технические свойства. Однако, они дают возможность повысить устойчивость окисленных битумов к старению путем изменения процессов структурообразования в битуме и адсорбции поверхностно-активных веществ на асфальтенах.

Компаундирование окисленного битума с остаточным битумом приводит к росту его остаточной пенетрации и снижению индексов старения.

Использование энергосберегающих добавок позволяет снизить температуры приготовления и уплотнения асфальтобетонных смесей, что способствует уменьшению термоокислительного старения битума, а значит повышению его долговечности.

Выводы. Разработанные технологии повышения устойчивости битумов и асфальтобетонов к старению позволят продлить сроки службы дорожных покрытий.

Ключевые слова: асфальтобетон, битум, энергосберегающая добавка, компаундирование, старение битума, поверхностно-активное вещество.