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EXPERIMENTAL EVALUATION OF STRENGTH FOR ASPHALT AND POLYMER MODIFIED ASPHALT CONCRETES AT LOW TEMPERATURES

Abstract. Tensile strength of asphalt concretes and polymer asphalt concretes was determined experimentally at low temperatures through two methods in the paper. According to the first method the ends of the sample were fixed inflexibly. Temperature was reduced from +20°C with the rate of 10°C/h till sample damage. Critical stress and temperature were determined. According to the second method samples of asphalt and polymer asphalt concrete are deformed under the scheme of direct tension with constant rate (approximately 1 mm/min) at a constant temperature equal to -20°C till damage. The stress, when the damage of the sample occur (splitting into parts), has been admitted as the tensile strength of material. Prior to testing the samples were previously conditioned for 1, 10, 20, 30 and 40 hours. Test results showed that duration of preliminary conditioning impacts greatly on strength and deformability of asphalt and polymer asphalt concretes. During deformation with constant rate at -20°C tensile strength of all tested asphalt and asphalt concretes decreases with the increase of thermostatic conditioning duration up to 10 hours and further increase of duration does not impact practically on it. Meanwhile the strength decrease of asphalt concretes with bitumens grade BND 70/100 and BND 100/130, polymer asphalt concretes with polymers Elvaloy 4170, Calprene 501 and Butonal NS 198 is 49%, 32 %, 24 %, 25 % and 29 % respectively. During cooling with constant rate the duration of thermostatic conditioning does not impact practically on critical characteristics of asphalt concrete with bitumen grade BND 100/130 and polymer asphalt concrete with polymer Butonal NS 198. For other asphalt and polymer asphalt concretes the critical temperature is reduced with the duration increase of thermostatic conditioning, and critical stress increases. For all tested asphalt and polymer asphalt concretes the reduction of critical temperature at maximum thermostatic conditioning (40 h) is 2-2.5°C. Maximum increase of critical stress, which also complies with maximum duration of thermostatic conditioning (40 h), for asphalt concrete with bitumen grade BND 70/130, polymer asphalt concretes (BND 100/130 + Elvaloy 4170) and (BND 100/130 + Calprene 501) is equal to 28.0 %, 6.1 % and 15.0 % respectively.

Key words: asphalt concrete, polymer modified asphalt concrete, tensile strength, low temperature, thermostatic conditioning duration.

1. Introduction. Low temperature cracking is one of the most frequently occurred types of mechanical destruction for asphalt concrete pavement of a highway. This type of destruction occurs all over the territory of Kazakhstan. In northern regions they often appear during the first period of road operation, and their number is increased during the course of time. It was determined in the scientific discovery No. 495 [1] that at consequent coolings in asphalt concrete pavement there occurred transversal thermal cracks and blocks, which were the forms of adaptation of thermodynamic system to the external conditions, and the average amount of them were proportional to logarithm of air cooling amount till the first critical temperature of pavement, and the first critical temperature value depends on climatic characteristics, as well as on rheological properties of asphalt concrete, and on its tensile strength in particular.

In accordance with the requirements of standard [2], before testing the asphalt concrete samples were thermally conditioned at testing temperatures for an hour. But in real road situations the temperature conditions of asphalt concrete layers for pavement structure vary within a wide range and the duration for the periods with specific temperature can be from several hours till several dozens of days. Taking into account the above, in this paper the samples of asphalt and polymer asphalt concretes were thermally conditioned before testing for 1, 10, 20, 30 and 40 hours at testing temperature equal to -20°C.

2. Materials and methods.

2.1. Bitumens and polymer bitumens. The following bitumen binders were used for preparing of asphalt and polymer asphalt concretes:

1) pure bitumen grade BND 70/100 and BND 100/130 of Pavlodar PetroChemical Plant (PPCP); 2) bitumen grade BND 100/130 PPCP with addition of polymer Elvaloy 4170 (1.4 % by weight of bitumen); 3) bitumen grade BND 100/130 of PPCP with addition of polymer Butonal NS 198 (3.0 %); 4) bitumen grade BND 100/130 of PPCP with addition of polymer Calprene 501(4.0 %).

Pure bitumens and modified bitumens comply with the requirements of standards [3, 4]. Basic standard indicators of pure bitumen and polymer bitumens are shown in Tables 1 and 2.

Table 1 – Basic standard indicators of the bitumen

Indicator	Measurement unit	Requirements of ST RK 1373-2013		Value	
		BND 70/100	BND 100/130	BND 70/100	BND 100/130
Penetration: - 25°C - 0°C	0.1 mm	71-100 22	101-130 30	75 32	110 37
Penetration Index PI	–	-1.0… +1.0	-1.0... +1.0	-0.87	-0.82
Tensility at temperature: - 25^0C - 0^0C	cm	≥ 75 ≥ 3.8	≥ 90 ≥ 4.0	118 5.2	135 6.6
Softening point	^{0}C	≥ 45	≥ 43	47.5	44.0
Fraas point	^{0}C	≤ -20	≤ -22	-28.5	-30.2
Dynamic viscosity, 60^0C	Pa·s	≥ 145	≥ 120	229.0	121.0
Kinematic viscosity	mm^2/s	≥ 250	≥ 180	428.0	329.0

Table 2– Basic standard indicators of the polymer bitumen

Indicator	Measu-rement unit	Requirements of ST RK 2534-2014		Value		
		PMB 50/70	PMB 100/130	BND 100/130 + Elvaloy 4170 – 1.4%	BND 100/130 + Calprene 501 – 4.0%	BND 100/130 + Butonal NS 198 – 3.0 %
Penetration: 25 °C	0.1 мм	≥ 51-70	≥ 70-100	86	58	83
Tensility at emperature: 25 ^{0}C	см	≥20	≥ 25	70	42.5	51.0
Softening point	ºC	≥62	≥ 60	63.5	73.0	61.0
Fraas point	ºC	≤ -16	≤ -18	-29.1	-32.3	-27.4
Ductility at temperature 25°C	%	≥60	≥60	72	84	71

2.2. Asphalt concretes and polymer asphalt concretes. Hot dense asphalt concretes and polymer asphalt concretes of type B that met the requirements of the Kazakhstan standard СТ РК 1225-2013 [5] were prepared with the use of aggregate fractions of 5–10 mm (20%); 10–15 mm (13%); and 15–20 mm (10%) from the Novo-Alekseevsk rock pit (Almaty region); sand of fraction 0–5 mm (50%) from the plant "Asphaltconcrete-1" (Almaty city); and activated mineral powder (7%) from the Kordai rock pit (Zhambyl region).

The bitumen content of grades PMB 50/70 and PMB 70/130 in the asphalt concretes and in the polymer asphalt concretes was 5.4% and 4.8% by weight of dry mineral material respectively. Basic standard indicators of the asphalt concretes and polymer asphalt concretes are shown in Tables 3 and 4, respectively. A granulometric composition curve for the mineral part of asphalt concretes and polymer asphalt concretes is shown in Figure 1.

Table 3 – Basic standard indicators of the asphalt concrete

Indicator	Measurement unit	Requirements of ST RK 1225-2013	Value	
			BND 70/100	BND 100/130
Average density	g/cm^3	-	2.39	2.38
Water saturation	%	1.5-4.0	2.9	3.4
Voids in mineral aggregate	%	≤ 19	15.1	16.3
Air void content in asphalt concrete	%	2.5-5.0	3.5	3.8
Compression strength at temperature:	MPa			
0°C		≤ 13.0	7.4	7.1
20°C		≥ 2.5	3.5	3.8
50°C		≥ 1.3	1.43	1.38
Water resistance	–	≥ 0.83	0.90	0.92
Shear resistance	MPa	≥ 0.38	0.40	0.39
Crack resistance	MPa	4.0-6.5	4.0	4.3

Table 4 – Basic standard indicators of the polymer asphalt concretes

Indicator	Measure-ment unit	Requirements of ST RK 1223-2013	Value		
			BND 100/130 + Elvaloy 4170 – 1,4 %	BND 100/130 + Calprene 501 – 4,0 %	BND 100/130 + Butonal NS 198 – 3,0 %
Average density	g/cm^3		2.41	2.41	2.405
Water saturation	%	1.5-3,0	2.5	2.2	2.6
Voids in mineral aggregate	%	≤ 19	16.0	14.3	16.6
Air void content in asphalt concrete	%	2.5-5.0	3.4	3.2	3.7
Compression strength at temperature:	MPa				
0 ^{0}C		≤ 9.0	7.3	6.8	7.7
50 ^{0}C		≥ 1.8	2.4	2.6	2.2
Water resistance	–	≥ 0.80	0.96	0.94	0.96
Shear resistance	MPa	≥ 0.45	0.53	0.49	0.47
Crack resistance	MPa	4-6	4.5	4.8	4.3

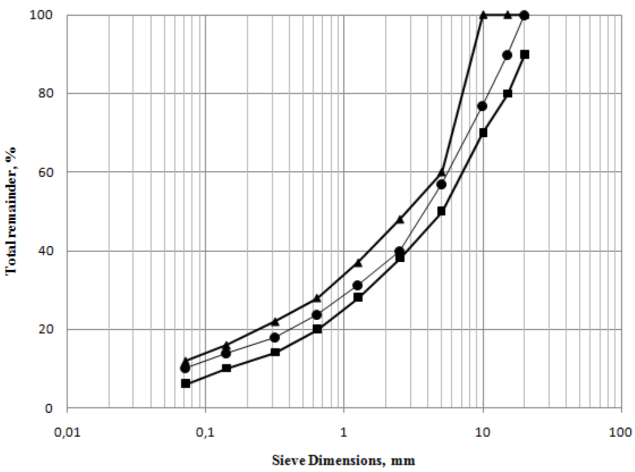

Figure 1 – A granulometric composition curve for the mineral part of asphalt concretes and polymer asphalt concretes

2.3. Samples preparing. Samples of the asphalt concretes and polymer asphalt concretes in the form of a rectangular prism with dimensions 5x5x16 cm (Figure 2) were manufactured as follows. First, the asphalt concrete and polymer concrete samples were prepared in the form of a square slab with dimensions 5x30.5x30.5 cm (Figure 3) using a Cooper compactor (UK, model CRT-RC2S) (Figure 4) according to the standard EN 12697-33 [6]. The samples were then cut from the asphalt concrete slabs in the form of a prism in a specially assembled installation. Deviations in sizes of the beams did not exceed 2 mm. Metal plates, designed to connect the samples to loaded installation and to measuring sensors, were glued to the ends of the samples and the samples were in the specially assembled installation for twenty-four hours to provide strength between the plates and the sample (Figure 5).

Figure 2 – Samples of the asphalt concretes and polymer asphalt concretes with dimension 5x5x16 cm to be tested

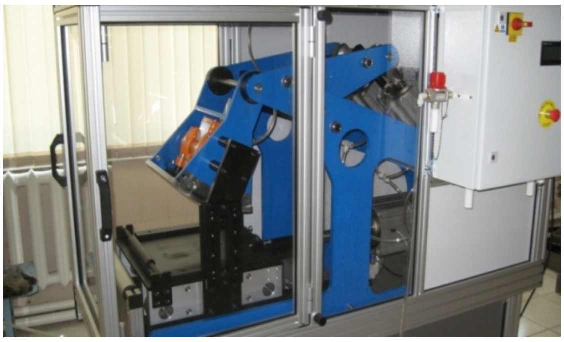

Figure 3 – The Cooper compactor CRT-RC2S

Figure 4 – A square slab of asphalt concrete with dimension 5x30.5x30.5 cm

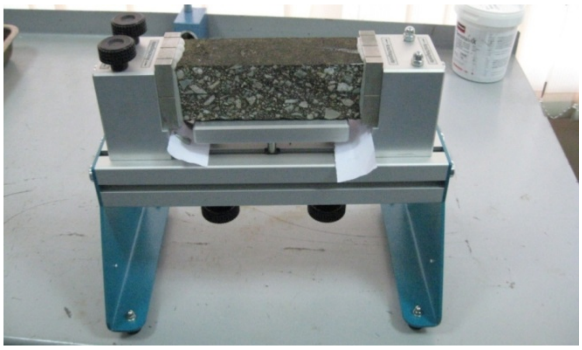

Figure 5 – The asphalt concrete sample with glued metal plates in a specially assembled installation

Before testing the samples of asphalt concretes and polymer asphalt concretes were installed into freezing chamber (Figure 6) with the temperature of -20°C, and they were thermally conditioned for 1, 10, 20, 30 and 40 hours.

Figure 6 – The asphalt concrete samples in a freezing chamber

Figure 7 – The asphalt concrete sample under test in a thermal chamber of TRAVIS

2.4. Samples testing. The samples of asphalt concretes and polymer asphalt concretes were tested in a special device TRAVIS (Figure 7), manufactured by Infratest company (Germany), according to two methods.

According to the first method the ends of the samples were unable to deform, i.e. they were fixed inflexibly. The temperature of a thermal chamber was reduced from +20°C with the rate of 10°C/h. Due to the limit of free deformation the thermal stress occurs and increases when the temperature reduces in the sample, and the sample is damaged at the moment when the thermal stress comes to maximum tensile stress. Thermal stress, when damage (splitting into parts) of the sample occurs, is called the critical stress σ_{cr}, and an adequate temperature is called a critical one T_{cr} [7, 8].

According to the second method the samples of asphalt concrete and polymer asphalt concrete are deformed under the scheme of direct tension with a constant rate (approximately 1 mm/min) at a constant temperature, equal to -20°C, till damage. The stress, when the damage (splitting into parts) of the sample occurs, is adopted as the tensile strength of the material.

3. Results and discussion.

3.1. Cooling with constant rate. As an example Figures 8, 9 and 10 show the graphs of temperature and thermal stress in the course of time, graph of thermal stress variation in asphalt concrete sample with

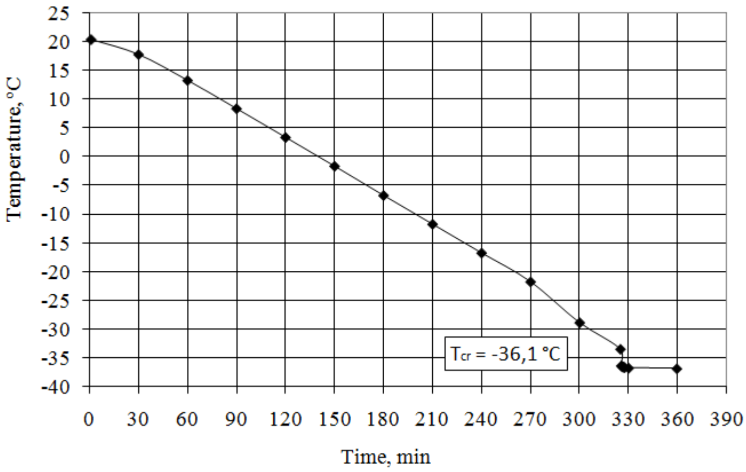

Figure 8 – Graph of temperature decrease during the course of time for the sample of asphalt concrete with bitumen grade BND 100/130 after preliminary thermal conditioning at the temperature of -20°C for one hour

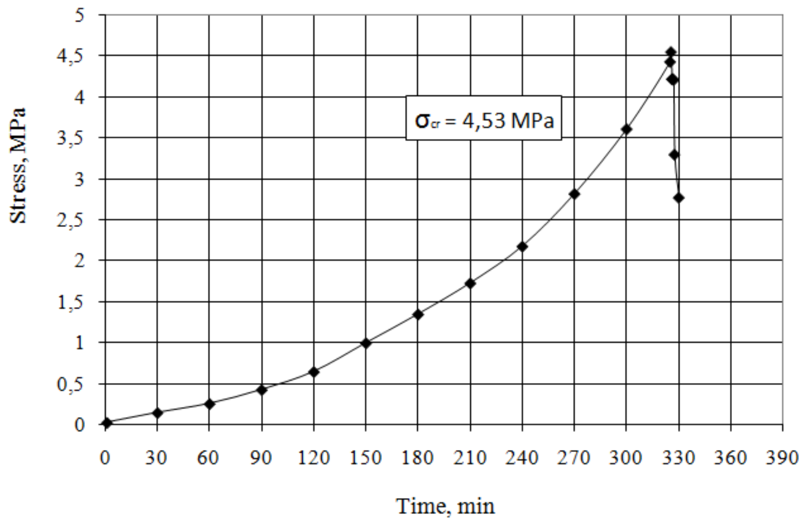

Figure 9 – Graph of thermal stress variation during the course of time for the sample of asphalt concrete with bitumen grade BND 100/130 after preliminary thermal conditioning at the temperature of -20°C for one hour

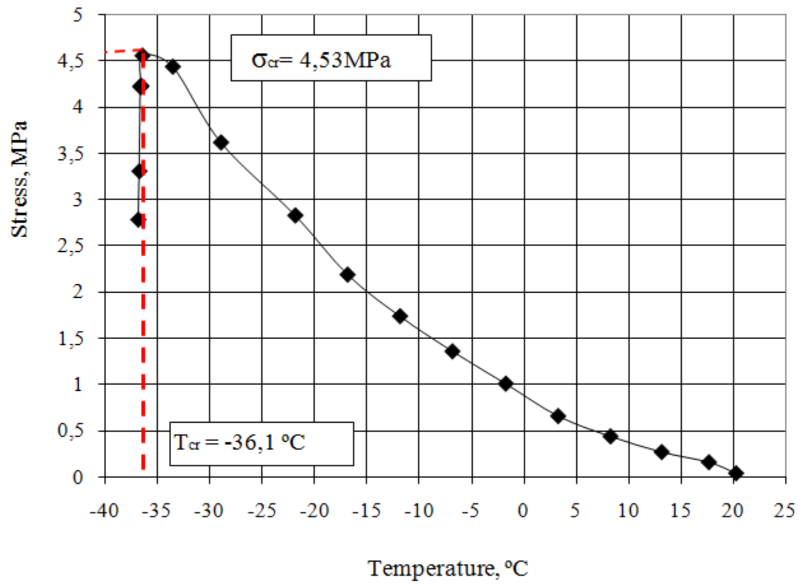

Figure 10 – Graph of thermal stress variation for the sample of asphalt concrete with bitumen grade BND 100/130 depending on temperature after preliminary thermal conditioning at the temperature of -20°C for one hour

bitumen grade BND 100/130 depending on temperature after preliminary thermal conditioning for one hour. As it is seen, the device TRAVIS provides temperature decrease of asphalt concrete sample in thermal chamber according to linear dependence during the course of time, and thermal stress in the sample varies non-linearly during the course of time. As a result, dependence of thermal stress on temperature is of non-linear character. We can see that the following has been determined as a result of test: critical stress and temperature are equal to σ_{cr} = 4.53 MPa and T_{cr} = -36.1°C.

The values of critical stresses and temperatures for the tested asphalt concretes and polymer asphalt concretes at different durations of preliminary thermal conditioning are shown in bar graphs (Figures 11 and 12), and the values of critical stress increase and critical temperature decrease are given in Tables 5 and 6 respectively. The data analysis of bar graphs and tables showed that preliminary thermal conditioning duration does not practically influence on critical characteristics (σ_{cr} и T_{cr}) of asphalt concrete with bitumen grade BND 100/130 and polymer asphalt concrete with bitumen grade BND 100/130 + Butonal NS 198. Critical characteristics of other asphalt concretes and polymer asphalt concretes vary with thermal

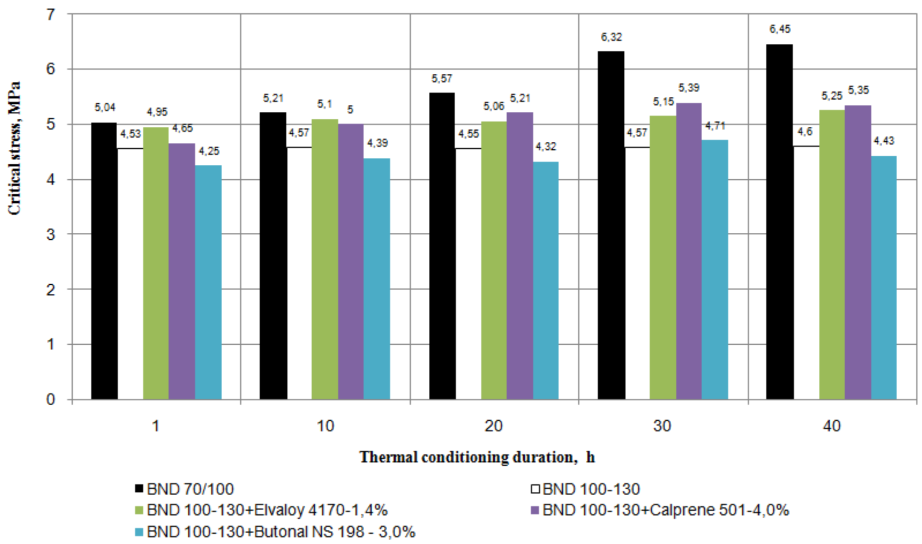

Figure 11 – Bar graph of critical tensile stresses of tested asphalt concretes and polymer asphalt concretes at different preliminary thermal conditioning durations

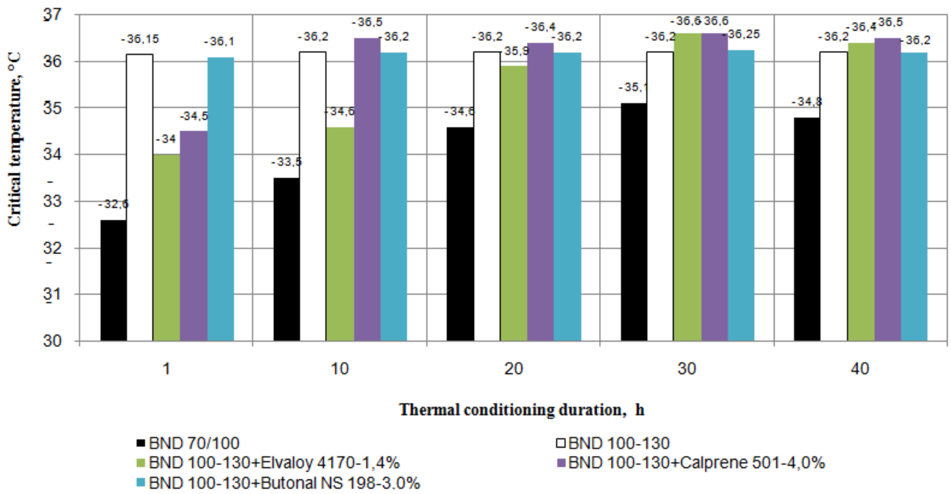

Figure 12 – Bar graph of critical temperatures at tension for tested asphalt concretes and polymer asphalt concretes at different preliminary thermal conditioning durations

Table 5 – Critical stress increase of asphalt concretes and polymer asphalt concretes at different preliminary thermal conditioning durations

Type of asphalt concrete	Increase of σ_{cr}, (%) at thermal conditioning duration (h)				
	1	10	20	30	40
Asphalt concrete, BND 70/100	0	3.4	10.5	25.4	28.0
Asphalt concrete, BND 100/130	0	0.4	0	0.4	1.1
Polymer asphalt concrete, BND 100/130 + Elvaloy 4170	0	3.0	2.2	4.0	6.1
Polymer asphalt concrete, BND 100/130 + Calprene 501	0	7.5	12.0	15.9	15.0
Polymer asphalt concrete, BND 100/130 + Butonal NS 198	0	3.3	1.6	10.8	4.2

Table 6 – Critical temperature decrease of asphalt concretes and polymer asphalt concretes at different preliminary thermal conditioning durations

Type of asphalt concrete	Decrease of T_{cr}, (°C) at thermal conditioning duration (h)				
	1	10	20	30	40
Asphalt concrete, BND 70/100	0	0.9	2.0	2.5	2.2
Asphalt concrete, BND 100/130	0	0.05	0.05	0.05	0.05
Polymer asphalt concrete, BND 100/130 + Elvaloy 4170	0	0.6	1.9	2.6	2.4
Polymer asphalt concrete, BND 100/130 + Calprene 501	0	2.0	1.9	2.1	2.0
Polymer asphalt concrete, BND 100/130 + Butonal NS 198	0	0.1	0.1	0.15	0.1

conditioning duration increase: critical stress increases, and critical temperature decreases. Practically for all these types of asphalt concrete the maximum critical temperature decrease (2-2.5°C) was obtained for the case of maximum thermal conditioning duration (40 h). Maximum critical stress increase, complying also with maximum thermal conditioning duration (40 h), for asphalt concrete with bitumen grade BND 70/130, polymer asphalt concretes (BND 100/130 + Elvaloy 4170) and (BND 100/130 + Calprene 501) is equal to 28.0 %, 6.1 % and 15.0 % respectively.

3.2. Deformation with constant rate. The strength values during direct tension for the tested asphalt concretes and polymer asphalt concretes at different durations of preliminary thermal conditioning are shown as bar graphs in Figure 13. As it can be seen, the strength of all tested asphalt concretes and polymer asphalt concretes decreases with thermal conditioning duration increase till 10 hours, and then remains practically constant. The strength decrease values of asphalt concretes and polymer asphalt concretes are given in Table 7. Strength decrease of asphalt concrete with bitumen grade BND 70/100 and BND 100/130, polymer asphalt concretes with polymers Elvaloy 4170, Calprene 501 and Butonal NS 198 is 49%, 32 %, 24 %, 25 % and 29 % respectively.

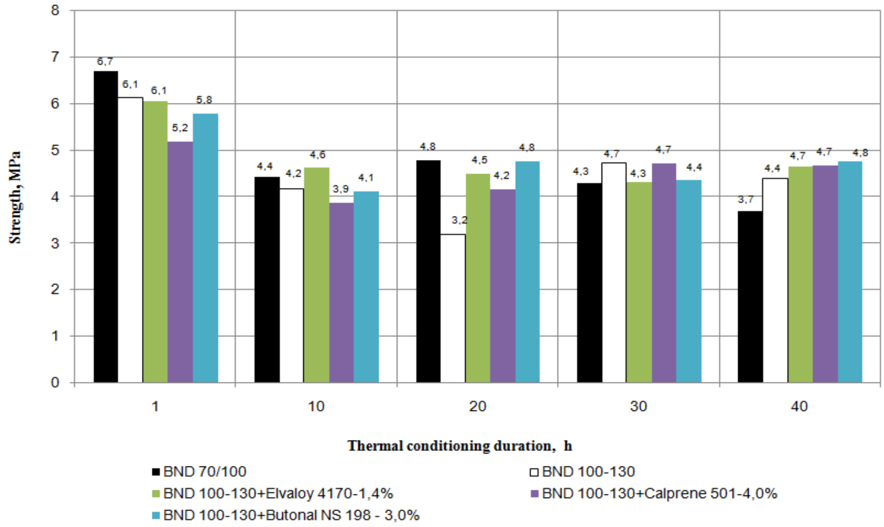

Figure 13 – Bar graph of tensile strength of the tested asphalt concretes and polymer asphalt concretes at different durations of preliminary thermal conditioning

Table 7 – Tensile strength decrease of the asphalt concretes and polymer asphalt concretes at different durations of preliminary thermal conditioning

Type of asphalt concrete	Strength decrease (%) at thermal conditioning duration (h)				
	1	10	20	30	40
Asphalt concrete, BND 70/100	0	48.8	28.5	36.0	44.9
Asphalt concrete, BND 100/130	0	32.0	47.7	22.8	28.2
Polymer asphalt concrete, BND 100/130 + Elvaloy 4170	0	23.5	25.8	28.9	23.2
Polymer asphalt concrete, BND 100/130 + Calprene 501	0	25.4	19.8	9.3	10.1
Polymer asphalt concrete, BND 100/130 + Butonal NS 198	0	28.8	17.6	24.4	17.6

Conclusion.

1. Preliminary thermal conditioning duration has an essential impact on the strength and deformability of asphalt concretes and polymer asphalt concretes.

2. During deformation with a constant rate at -20°C the tensile strength of all tested asphalt concretes and polymer asphalt concretes decreases with thermal conditioning duration increase till 10 hours, and further duration increase does not have practical impact. Meanwhile, the strength decrease of asphalt concretes with bitumen grade BND 70/100 and BND 100/130, polymer asphalt concretes with polymers Elvaloy 4170, Calprene 501 and Butonal NS 198 is 49%, 32 %, 24 %, 25% and 29 % respectively.

3. During cooling with a constant rate the thermal conditioning duration does not practically influence on critical characteristics of asphalt concrete with bitumen grade BND 100/130 and polymer asphalt concrete with polymer Butonal NS 198. For other asphalt concretes and polymer asphalt concretes the critical temperature decreases and critical stress increases with thermal conditioning duration increase. For all tested asphalt concretes and polymer asphalt concretes the critical temperature decrease is 2-2.5°C at maximum thermal conditioning duration (40 h). Maximum critical stress increase, complying also with maximum thermal conditioning duration (40 h), for asphalt concrete with bitumen grade BND 70/130, polymer asphalt concretes (BND 100/130 + Elvaloy 4170) and (BND 100/130 + Calprene 501) is equal to 28.0 %, 6.1 % and 15.0 % respectively.

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ТӨМЕНГІ ТЕМПЕРАТУРАЛАРДА АСФАЛЬТ- ЖӘНЕ ПОЛИМЕРАСФАЛЬТБЕТОНДАРДЫҢ БЕРІКТІГІН ТӘЖРИБЕЛІК БАҒАЛАУ

Аннотация. Жұмыста тәжрибелік жолмен асфальтбетон мен полимерасфальтбетонның төменгі температураларда созылу кезіндегі беріктігі екі әдіс бойынша анықталды. Бірінші әдіс бойынша сынамалардың ұштары қатты бекітілген. Температура 10 °С/сағ жылдамдықта +20 °С-ден сынаманың бұзылуына дейін төмендеді. Қауіпті кернеуі мен температура анықталды. Екінші әдіс бойынша асфальт- және полимерасфальтбетондардың сынамалары -20 °С-ге тең тұрақты температурада тұрақты жылдамдықта (1 мм/мин шамасында) тура созылу сұлбасы бойынша бұзылуға дейін деформацияланады. Сынама бұзылатын (бөліктерге бөлінуі) кернеу материалдың созылу кезіндегі беріктігі ретінде қабылданады. Сынаудың алдында сынамалар алдын ала 1, 10, 20, 30 және 40 сағат бойы термостатталды. Сынау нәтижелері алдын ала термостаттаудың ұзақтығы асфальт- және полимерасфальтбетондардың беріктігіне және деформациялануына айтарлықтай әсер ететінін көрсетті. Сыналған барлық асфальт- және полимерасфальтбетондардың созылу кезіндегі беріктігі -20 °С-де тұрақты жылдамдықта термостаттау ұзақтығын 10 сағатқа дейін арттырғанда төмендейді және одан кейінгі ұзақтықты арттыру ешқандай әсер етпейді. Сонымен бірге, БНД 70/100 және БНД 100/130 битум маркасы бар асфальтбетондардың және Elvaloy 4170, Calprene 501 және Butonal NS 198 полимерлері бар полимерасфальтбетондардың беріктігінің төмендеуі 49%, 32 %, 24 %, 25 % және 29 % тең. Тұрақты жылдамдықта салқындату кезінде термостаттау ұзақтығы БНД 100/130 битум маркасы бар асфальтбетонның және Butonal NS 198 полимері бар полимерасфальтбетонның критикалық сипаттамаларына әсер етпейді. Басқа асфальт- және полимерасфальтбетондарда термостаттау ұзақтығы артқан сайын критикалық температурасы төмендеп, критикалық кернеу артады. Барлық сыналған асфальт- және полимерасфальтбетондардың критикалық температурасының төмендеуі ең жоғары термастаттау кезінде (40 с) 2-2,5 °С-қа тең. Ең жоғары термастаттауға (40 с) сәйкес келетін критикалық кернеудің барынша көп артуы БНД 70/130 битум маркасы бар асфальтбетон және тұтқырғыштары бар полимерасфальтбетондар үшін (БНД 100/130 + Elvaloy 4170) және (БНД 100/130 + Calprene 501) 28,0%, 6,1% және 15,0%-ке тең.

Тірек сөздер: асфальтбетон, полимерасфальтбетон, созылу беріктігі, төменгі температура, термостаттау ұзақтығы.

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ЭКСПЕРИМЕНТАЛЬНАЯ ОЦЕНКА ПРОЧНОСТИ АСФАЛЬТО- И ПОЛИМЕРАСФАЛЬТОБЕТОНОВ ПРИ НИЗКИХ ТЕМПЕРАТУРАХ

Аннотация. В работе экспериментальным путем определена прочность при растяжении асфальтобетонов и полимерасфальтобетонов при низких температурах по двум методам. По первому методу концы образцов были закреплены жестко. Температура понижалась с +20 °С со скоростью 10 °С/ч до разрушения образцов. Определялись критические напряжение и температура. По второй методике образцы асфальто- и полимерасфальтобетонов деформируются по схеме прямого растяжения с постоянной скоростью (около 1 мм/мин) при постоянной температуре, равной -20 °С, до разрушения. Напряжение, при котором происходит разрушение (разделение на части) образца, принимается как прочность материала при растяжении. Перед испытанием образцы были предварительно термостатированы в течение 1, 10, 20, 30 и 40 часов. Результаты испытания показали, что продолжительность предварительного термостатирования оказывает существенное влияние на прочность и деформируемость асфальто- и полимерасфальтобетонов. При деформировании с постоянной скоростью при -20 °С прочность всех испытанных асфальто- и полимерасфальтобетонов уменьшается при увеличении продолжительности термостатирования до 10 часов и дальнейшее увеличение продолжительности практически не влияет. При этом уменьшение прочности асфальтобетонов с битумами марок БНД 70/100 и БНД 100/130, полимерасфальтобетонов с полимерами Elvaloy 4170, Calprene 501 и Butonal NS 198 составляет 49%, 32 %, 24 %, 25 % и 29 % соответственно. При охлаждении с постоянной скоростью продолжительность термостатирования практически не влияет на критические характеристики асфальтобетона с битумом марки БНД 100/130 и полимерасфальтобетона с полимером Butonal NS 198. У других асфальто- и полимерасфальтобетонов с увеличением продолжительности термостатирования критическая температура уменьшается, а критическое напряжение увеличивается. Для всех испытанных асфальто- и полимерасфальтобетонов понижение критической температуры при максимальной продолжительности термостатирования (40 ч) составляет 2-2,5 °С. Максимальное увеличение критического напряжения, соответствующее также максимальной продолжительности термостатирования (40 ч), для асфальтобетона с битумом марки БНД 70/130, полимерасфальтобетонов (БНД 100/130 + Elvaloy 4170) и (БНД 100/130 + Calprene 501) равно 28,0 %, 6,1 % и 15,0 % соответственно.

Ключевые слова: асфальтобетон, полимерасфальтобетон, прочность при растяжении, низкая температура, длительность термостатирования.

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