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Asphalt concrete pavement reinforced with chemical fibers

Viktor Lukashevich[1,*], *Igor* Efanov[1], *Viktor* Vlasov[1], and *Olga* Lukashevich[1]

[1]Tomsk State University of Architecture and Building, 634003 Tomsk, Russia

Abstract. Asphalt concrete pavement which is currently built in accordance with the existing requirements does not withstand the standard service life. Various kinds of damages occur. Fiber reinforcement of asphalt concretes is one of the effective means to deal with deformations and fractures of road pavements, such as rutting, buckling, crack formation and shear. Chemical fibers serving as reinforcement are of great concern herein. The major purpose of this work was evaluation of reinforcement fibers resistance to natural environment and climatic impacts within the conditions of experimental production construction and studying compactibility of asphalt concrete mixture with fiber reinforcement. Infrared spectroscopy and physical-chemical investigations of fibers were used to study changing properties of fiber-forming polymer. Compactibility of asphalt concrete mixture with fiber reinforcement was determined upon compaction factor. Research results revealed insignificant influence of natural environment and climatic impacts on the properties of fiber reinforcement material. In order to obtain the standard compaction factor of asphalt concrete additional compacting impact is not required.

Introduction

Asphalt concrete pavements have been distinguished with economic feasibility, simplicity of construction, maintenance and repair and possibility of the material to be recovered and reused, thus resulting in their wide application on the roads of the majority of world countries. However, their strength properties are largely dependent on the ambient temperature which makes it one of the major shortages of pavements of such kinds. At high positive temperatures asphalt concrete possesses low resistance to shear load, while under negative temperatures it lacks sufficient crack resistance. Hence, it results in occurring deformations of asphalt concrete pavements (rutting, crack formation, buckling and shear).

Both processing and constructive techniques are applied to reduce the intensity of deformations occurrence. Fiber reinforcement of asphalt concrete mixtures has been proven to be the most effective technique among them, as confirmed by the studies in [1-3]. Belarusian and Russian scientists A.V. Akulich, I.P. Gamelyak, Y.N. Kovalev proved that fiber-reinforced asphalt concretes (FRAC) have higher shear strength at high temperatures,

*Corresponding author: vnluc@yandex.ru

better tensile strength and enhanced deformability under negative temperatures and they are more resilient to fatigue failures [4-9].

In spite of the fact that a significant amount of studies are devoted to FRAC, still there are a number of issues to be investigated. The influence of natural environment and climate on the properties of reinforcement fibers is insufficiently studied. The issues of compactibility of asphalt concrete mixtures subject to chemical fiber reinforcement have also not been investigated yet. The present paper aims to study the influence of natural environment and climate on physical-chemical properties of fiber reinforcement; and to determine compactibility of FRAC mixture within the conditions of experimental production construction.

Materials and methods

The resistance of reinforcement fibers was investigated in laboratory and experimental production conditions. Rope-shaped nylon fibers with the linear density 250 tex. were randomly selected. They were further divided into four groups of specimens, 50 meters long each. The specimens in the first group were reference ones and they were not subjected to treatment. Specimens of the other groups were placed in bitumen, then taken out and purified in hexane. Oil bitumen (Russian grade BND 90/130) was used for treatment, as it is most commonly used in road-construction companies of West Siberia. Hexane was used for purification of fibers from oil bitumen due to its being the most pure product having clearly distinctive characteristic absorption bands as seen from infrared spectroscopy investigations; moreover, hexane has slight influence on the general nature of changes in specimens under study.

Ageing of specimens was performed using artificial weather apparatus IP-1-3 brand, (weathering machine). The influence of atmospheric factors of moderately continental, subtropical and northern climates was imitated with the aid of this machine. The machine looks like an isolated chamber. Inside the chamber a cylinder is mounted (a drum to fasten and move the specimens) which rotates with the velocity of 1 circle per minute. In the center of the drum there are two arc lamps and two mercury quartz lamps PRK-2 of ultraviolet lighting. They provide emission which is close to sunlight by its spectral composition. The integrated radiant flux surface density (730±130) W/m^2 is provided inside the machine while flux density of ultraviolet lighting per unit area is (30±5) W/m^2. The machine has two spray systems: the first is for simulating humidity conditions in the chamber, the second is for watering of the specimens. The machine has panel board, electric motor for drum drive, gear box, resistors for arc lamps, fan, manometric thermometers (self-recording and indicating), nozzles for watering of the specimens, automatic valve, cycle timer to set the watering mode. The fibers were tested in artificial weather apparatus at the mode simulating northern climatic conditions. The number of impact cycles of climatic factors corresponded to pavement service life of 18 years. After treatment in climatic chamber, the specimens were purified from bitumen by hexane.

Degree of compaction of FRAC mixture was determined in the conditions of experimental production works. Compaction factor was determined according to the methodology stated by the regulatory documents [10]. Infrared spectra of the fibers were recorded using “Specord M-80” spectrophotometer. Spectra identification was performed with the aid of the reference data [11].

Results

The properties of asphalt concrete obtained according to the conventional technologies are characterized by interactions within the system “mineral – bitumen”. The adhesion between the particles of mineral material in asphalt concrete mixture and therefore, the strength of asphalt concrete is primarily provided by absorption-solvation bitumen shells which are there on the surface of mineral particles. It should be noted that the adhesion of each particle is performed only by the neighboring particles surrounding it (short-range order adhesion). There is no adhesion between the mineral particle and the particles separated from it by the rows of other particles (long-range order adhesion). The nature of these interactions changes in the presence of reinforcement fibers.

The basic factor enabling to lower the intensity of occurrence of such road pavements deformations as rutting, crack formation, buckling and shear is the presence of fiber reinforcement in asphalt concrete composition. These segments of reinforcement are placed between the grains of mineral material and are in the absorption-solvation bitumen shells. Passing through the patterned bitumen layers surrounding several particles, reinforcement fibers are hooked in them thus providing additional adhesion between these particles. In this way, adhesion between the particles of fiber-reinforced materials is basically provided by the two types of cohesion: by the patterned bitumen layers and by the fiber reinforcement hooked in these layers. Moreover, each particle in fiber-reinforced materials is bonded not only with the surrounding particles (short-range order adhesion) but also with the particles separated from it by several rows of other particles (long-range order adhesion). Reinforcement fibers are bonded with each other due to their location in the patterned bitumen layer. Thus, they form space lattice in asphalt concrete mixture which encircles mineral particles within the conglomerate composition. It results in substantial improvement of all the properties of asphalt concrete mixture.

Fiber reinforcement of asphalt concrete requires provision of established space lattice from segments of chemical fibers, uniformly distributed throughout the total volume. In case this condition is not followed, the asphalt concrete layer will not be equal in strength, as separate parts of pavement will not be covered by reinforcing space lattice. The lower strength properties of such areas will cause initiation of fractures, specifically in these areas; the effect of fiber reinforcement will not be accomplished.

The increase of strength and rheological properties in fiber reinforcement occurs in consequence of extended structures formation from reinforcement fibers. Closely spaced fibers are bonded into single structures – strength clusters. The size and shape of such structures (clusters) and the strength of fibers determine the properties of reinforced materials [9]. In this regard, it is of great importance to study the resistance of reinforcement fibers to the impact of oil bitumen and natural environment and climatic impacts. This refers in particular to periodical moistening and drying, heating and cooling, freezing and thawing. One of the major factors leading to destruction of polymer materials is ultraviolet lighting impact.

Investigations of resistance of reinforcement fibers to the impact of oil bitumen and natural environment and climatic impacts were carried out in laboratory and in the conditions of experimental production works.

The properties of four groups of reinforcement specimens from nylon rope-shaped fibers were investigated:

1 – reference specimens (without treatment);

2 – specimens placed in bitumen, taken out and purified in hexane;

3 – specimens placed in bitumen, aged in weathering machine for 18 hours, purified in hexane;

4 – specimens placed in asphalt concrete on the experimental plot of road pavement and taken out after 7 years of operation.

The fourth group of specimens was used in the process of experimental production works on construction of experimental plot of road pavement. Fine-grained fiber-reinforced dense asphalt concrete of B type was used for that purpose. It was compacted from hot mixture and its properties coincided to the requirements of Russian National State Standard GOST 9128[12]. Experimental production works on construction of experimental plot were carried out on the basis of the republican automobile road department "Gorno-Altayavtodor" in 2010 by the Road Operator No.217 on the approach to Gorno-Altaysk. In 2017 reinforcement fibers were taken out from the road pavement and subjected to laboratory studies. During experimental production works compactibility of fiber-reinforced asphalt mixtures was also investigated. In these conditions, the intensity of compacting impact was identical to the intensity used while compacting asphalt concrete mixtures of conventional composition (unreinforced mixtures).

All four groups of specimens of nylon rope-shaped fibers were subjected to chemical and physical-mechanical testing. The results of physical-mechanical testing of nylon rope-shaped fibers are given in Table 1.

Table 1. Results of physical-mechanical testing of nylon rope-shaped fibers.

Parameter	Unit of measurement	Specimen No.1	Specimen No.2	Specimen No.3	Specimen No.4
Specific viscosity	-	2.456	2.5	2.52	2.51
Content of extractable	%	2.6	2.0	1.5	1.8
substances		0.2	0.2	0.7	0.5
Thermal stability	^{0}C	215	215	216	216
Melting temperature	g/tex	15.9	19.3	8.1	14.7
Breaking strength	%	45.6	47.7	26.9	34.8
Breaking elongation					

Analyzing the data given in the table it can be noted that specific viscosity and thermal stability in all four specimens changed insignificantly. After fiber treatment with bitumen the value of breaking strength increased, however, after 18 years simulated in the chamber, this value decreased by almost 50%. This can be explained by the fact that artificial weather apparatus provides more severe conditions than the real ones. In the weather machine ultraviolet emission impacts the nylon fiber, which is protected just by the adsorption layer of oil bitumen. However, in the real conditions it is protected by the asphalt concrete layer, which reduces significantly the intensity of natural environment and climatic impacts. In the real conditions breaking strength decreased by only 8%. The processes of fibers ageing also resulted in decrease in breaking elongation. After weather machine this value decreased by 65% and in the real conditions by 31%. The results of investigations of fiber specimens using infrared spectroscopy are given in Figure 1.

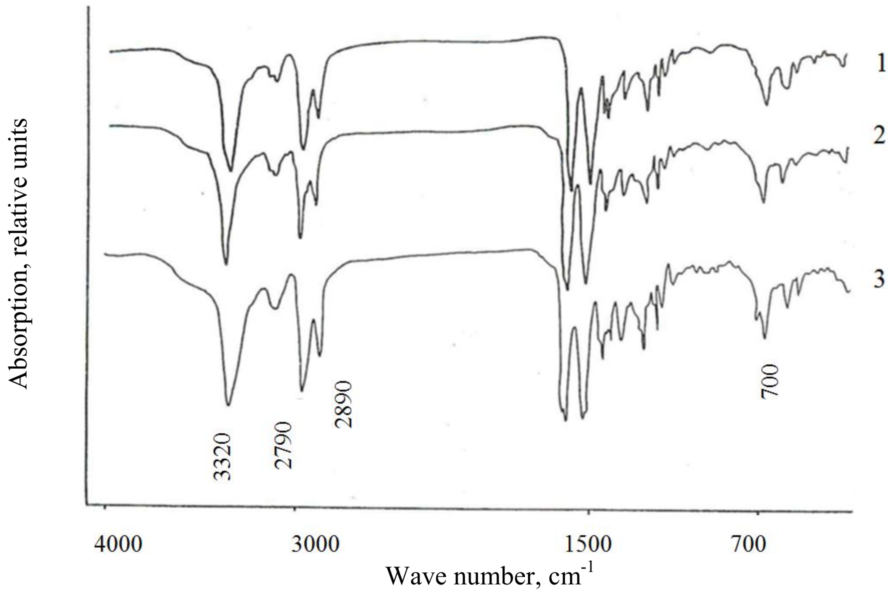

Fig. 1. IR spectra of nylon rope-shaped fibers: 1 – reference nylon fiber; 2 – nylon rope-shaped fiber treated with bitumen, hexane purified; 3 – nylon rope-shaped fiber taken out from asphalt concrete pavement, hexane purified.

It can be seen from Figure 1 that IR spectra of the initial fiber and the one taken out from the road pavement is characterized by absorption bands in the area 1640-1690 cm^{-1} (the peak with absorption bands 1660 cm^{-1} - "amide I band" of carbonyl group C=O). The free group N-H conditions in addition to the band C=O. The same bands of stretch vibrations as N-H when 3050-3550 cm^{-1} (the peak is undertaken by transform with absorption band 3320 cm^{-1}) and deformation vibrations –NH- when 1530-1570 cm^{-1} (the peak 1560 cm^{-1}). Absorption with the band 1300 cm^{-1} is mostly connected with the vibrations C-N. This vibration is also overlapped with the vibrations NH "amide III band". Deformation vibrations N-H provide rather intensive wide brand in the area 650-900 cm^{-1} (the peak 700 cm^{-1}). Weak bands in the area 1030-1230 cm^{-1} correspond to stretch vibrations CN. Their location slightly differs from the stretch vibrations C-C. Brands 2970 and 2890 cm^{-1} (duplet) can be referred to the stretch vibrations C-H. As an indirect proof of such reference the increase in intensity of these bands of nylon fiber specimen treated by bitumen, aged and hexane purified may serve. These data testify that during natural environment and climatic impacts fiber-forming polymer did not experience any significant changes.

Upon the completion of experimental production works the compaction factor of fiber-reinforced asphalt concrete and asphalt concrete made according to the conventional technology was determined. It was established that the compaction factor in both cases satisfied the value established in the regulatory documents, i.e. 0.98 [10].

Conclusion

As a result of experimental production works on construction of experimental plot of road pavement from FRAC the following conclusions were made. The layer of asphalt concrete pavement serves as a screen protecting reinforcement fibers from natural environment and climatic impacts. The properties of reinforcement fibers do not undertake significant changes herewith. In the real conditions of road pavement operation the value of breaking strength decreased by only 8%.

The obtained results testify that fiber reinforcement from nylon rope-shaped fiber can fulfill the reinforcing functions during the whole lifecycle of asphalt concrete pavement. In order to obtain the reference compaction factor of asphalt concrete additional compacting impact is not required. Further research will be focused on experimental works determining the influence of various reinforcement factors on compactibility of fiber-reinforced asphalt concrete mixtures.

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