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LABORATORY PERFORMANCE ASSESSMENT OF FIBER REINFORCED ASPHALT MIXES

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ABSTRACT

Utilization of asphalt mixes can be in Czech Republic divided in pavements with standard traffic loading and climate conditions, as well as in pavements with increased requirements on their performance and resistance against occurring impacts (extreme traffic intensities, untypical traffic on aprons, junctions with extreme effects of acceleration and deceleration, eventually sections with higher longitudinal slopes or changing climate conditions). In these cases often stiffer or more fatigue resistant mixes combined with PmBs should be used. Because sections with such impacts often are shorter the change in mix design might not always be cost effective and technically can cause other problems (change in compaction, construction joints). An alternative for performance adequate pavement is fiber improved mix by scattered 3D reinforcement. As one of present applied research works the benefit of fibers and comparison with other technical solutions has been assessed at CTU in Prague. The results so far have shown increased stiffness, whereas the fibers increase this performance characteristic especially in the range of higher temperatures. Improvement in resistance to permanent deformations could be demonstrated and challenging findings could be found in the fatigue testing compared as well. Results of the experiments will be presented in the paper.

KEY WORDS: fiber reinforced asphalt, kevlar fibers, stiffness, permanent deformations, characteristics in low temperature range, fatigue.

1. INTRODUCTION

The process of developing a construction material starts right at the moment of production or use in construction structures. The process aims to improve the material's useful characteristics which affect the behavior of the structure it is incorporated in. Improvements are achieved through reduction or removal of the material's negative effect on the future structures without affecting the positive characteristics based on which the material is used.

In road construction we want the materials used for the individual structural layers to have improved resistance to the load at work, weather and climate effects. With asphalt mixtures, modified binders, surface reinforcement at the bond of two layers or 3D reinforcement evenly distributed in the mixture can be applied. An advantage of 3D reinforcement in comparison to areal reinforcement is its isotropic behavior.

Due to its geography, the Czech Republic is a transit country. Despite the impact of the economic crisis (hopefully at its end now) we cannot expect the traffic load on our road to significantly decrease. Therefore, we have to keep implementing measures to reduce the negative effects of high traffic loads on the pavement structure. On heavily loaded routes, technologies with high stiffness modules are applied in the binder and base course; the life of the structural layers is greatly emphasized and increased by the use of modified bituminous binders. Even in cities, places with heavy loads can be found. Those spots are specifically loaded by characteristic traffic, i.e. effect of tangential forces acting in all directions, impact of static traffic. Typical spots are junctions, curves with small radiuses, zebra crossings. One of the alternatives of dealing with the aforementioned situations is the application of 3D reinforcement in asphalt mixtures.

2. ASPHALT MIXTURE REINFORCEMENT

Fibers can be encountered in asphalt mixtures in SMA or PA mixture types where cellulose fibers are used to act as binder carriers. They are sometimes used even in AC mixtures if these contain a larger proportion of bitumen. Other fibers, like acrylic or other, can also be used as bitumen carriers; we even know asphalt layer reinforcement in the form of geo-synthetics (we can speak of so-called 2D reinforcement) which are mostly applied in pavement repair and maintenance technologies. However, they are also found in new construction where hydraulically compressed materials are used in the subbase layers of the pavement structure. This form of fiber application has no, or just limited impact, on the mechanical and functional characteristics of asphalt mixtures. The inclusion of geo-synthetics in the pavement structure prevents cracks propagation into asphalt layers from hydraulically bond sub-base layers or during reconstructions of rigid pavements. Another positive characteristic is the reduction of the scope of permanent deformation occurrence.

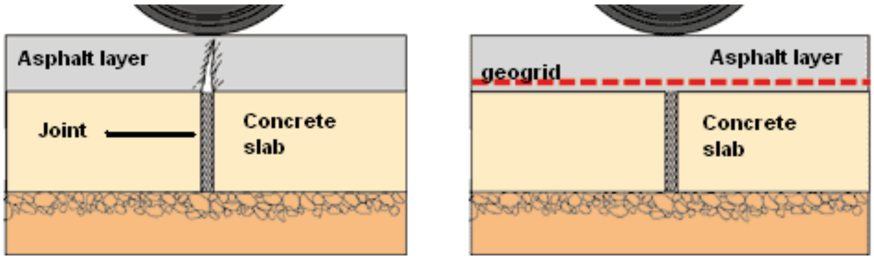

Figure 1 Utilization of geosynthetic reinforcement in the pavement structure

2.1 Specification of 3D Reinforcement

The use of fibers as distributed reinforcement has been known in the long term in the field of concrete structures and components. An analogous principle can be applied in asphalt mixtures. In principle, the reinforcement is expected to increase the resistance of the structural layer against permanent deformation, to increase stiffness and improve its life. All of those positive features can be used both in rural areas and, particularly, locally on local roads.

In cities, we can encounter spots characterized by typical defects like "rutting", transverse "corrugations" in front of junctions, zebra crossings or at steeply sloped places. The problem can be addressed by the application of stiffer mixtures. However, these are short segments where a change of the mixture applied for a more resistant one induces technological changes in the production, laying and compacting. The problems may be minimized by using fibrous reinforcement in the mixtures while the asphalt mixture composition or laying process technology undergoes no change at all. Even in the case of small mixing plants which only use a single container for bitumen the quality of the mixture may be improved by adding fibers.

A great advantage of the fibers (3D reinforcement) in comparison to areal reinforcement is their significantly smaller impact on human factor failure during application thereof. The fibers are beneficial because the technology of laying a fiber-reinforced mixture is identical to that for a fiber-free mixture; no special training for companies involved in the laying is necessary.

The fibers are added in the dry mixing process during the asphalt mixture production. This ensures an even distribution thereof in the entire volume; therefore, we can expect their effect to be isotropic. The good functioning of the reinforcement in the asphalt mixture is affected by perfect distribution and interaction with the aggregate and binder. The length of the fibers used should be in accordance with the maximum grain size in the mixture, see fig. 2.

3. EXPERIMENTAL TESTING

A set of laboratory testing was intended to verify the effects of reinforcement distributed in asphalt mixes. The testing was performed in two stages. In stage one, the effect of fiber addition on an asphalt mixture was compared, i.e. what benefits there are for fiber dosage in relation to selected characteristics when the composition, or binder applied, was not modified. In stage two, mixtures with 50/70 bitumen and fibers were compared to mixtures where polymer modified binders were used. The scope of the testing methods was not always identical and has been added to continuously. The testing aims to research the benefits of fibers in asphalt mixes in laboratory testing which is typical for the Czech Republic. Generally the specialist public seeks verification of foreign experience by an independent domestic expert institution.

In our case, FORTA FI fibers were used; these are combination of aramide (Kevlar) and poly-olephin fibers. The fibers were dosed in the mixture in quantities of 0.5 kg per 1 tone of asphalt mixture. Detailed information on the extensive testing of the effects of such fibers in asphalt mixes as performed at Arizona State University is available in [1,2].

Figure 2 and 3 Dispersion of the fibers in mineral skeleton related to the length of the fiber, mix of FORTA fibers for Hot Mix Asphalt

The laboratory test program described in [1,2[conducted within the framework of the research included the following tests: 3D shear strength, dynamic (complex) modulus, repetitive load for permanent deformation characteristics, flexural strength and stiffness determination on test beams with the effect of fatigue behavior, splitting tensile strength on cylindrical specimens to determine the occurrence of thermal (frost-induced) cracks, crack propagation assessment test.

As ensued from the work performed, the optimum dosage of fiber is above the level of 1 pound (0.454 kg) of fiber per 1 tone of mixture. The dosage of 2 pounds (0.908 kg) of fiber per tone of mixture did not have positive effect on the characteristics researched. The findings show that the dosage of fiber just like the dosage of any other additives needs work to optimize the quantity of "improving" materials added.

Within the framework of the testing at CTU, an extensive set of work which focused on monitoring of several types of fiber, i.e. cellulose, mineral and synthetic fibers, in AC and SMA mixtures has been defined. With respect to the scope of the paper, only results of the poly-olephin and aramide fibers in AC and SMA mixtures will be presented. The characteristics monitored were as follows: stiffness modulus, fatigue, resistance to permanent deformation, water susceptibility; crack propagation test with specimens according to the new standard CSN EN 12697- 44 has been performed as well.

3.1 Assessed Laboratory Mixes

The testing was conducted with typical mixtures used in CZE in wearing and binder courses. A summary is given in table 1. The mixtures where fibers were applied are marked by the FR acronym (Fiber Reinforced) preceding the mixture name. The binder, quarry and aggregate type are also given for the mixtures. In total, there were two types of asphalt concrete for wearing courses, one AC mix for binder course and one SMA mix. No exact composition was known for mixtures produced by Eurovia Services s.r.o..

Table 1 Overview of assessed asphalt mixes

Asphalt mix	Mix type	Used bitumen	Quarry	Aggregates
ACO 11 S_1	ACO 11 S	50/70	Markovice	Hornblende schist
FR ACO 11 S_1	ACO 11 S	50/70	Markovice	Hornblende schist
ACO 11 S_2	ACO 11 S	PmB 45/80-55	Mix design of Eurovia	
FR ACO 11 S_2	ACO 11 S	50/70	Mix design of Eurovia	
ACO 11 + _3	ACO 11 +	70/100	Chlum	Phonolite
FR ACO 11+_3	ACO 11 +	70/100	Chlum	Phonolite
ACL 22 S	ACL 22 S	PmB 25-55/60	Mix design of Eurovia	
FR ACL 22 S	ACL 22 S	50/70	Mix design of Eurovia	
SMA 11 S	SMA 11 S	50/70	Markovice	Hornblende schist
FR SMA 11 S	SMA 11 S	50/70	Markovice	Hornblende schist

3.2 Stiffness Modulus

Stiffness modulus of asphalt mixes was determined by non-destructive method according to CSN EN 12697-26. The stiffness modules is measures on various types of compacted test specimens under the effect of forced steady harmonious (sinusoid) load or other types of controlled load and the application of various support types. 4PB-PR and IT-CY test methods (see fig. 4 and 5) were applied within the framework of the work.

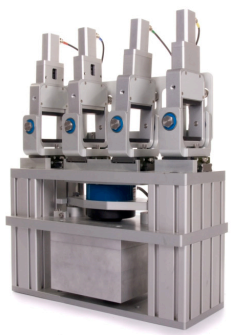

Figure 4 Test device for the determination of stiffness modulus by IT-CY method (left) and by 4 PB-PR method (right)

The measurement results are given in the following tables 2 and 3. Based on the values obtained, we can note that the fibrous additions increase the stiffness of the mixtures. The benefits are demonstrated more under higher temperatures. The comparison of benefits by IT-CY method reached similar increases for both AC and SMA mixtures. The 4PB-PR test did not find modulus increase as much as the IT-CY but, again, a significant benefit was detected under higher temperatures as well as in the case of lower frequencies which are characteristic for slow traffic. The results are in accordance with the test of asphalt mixture resistance to permanent deformation. The comparison of mixtures with unmodified binders and fibers with modified binders yielded similar results. In this case, both products are interchangeable.

Table 2 Stiffness modulus determined by 4 BP-PR test procedure

Asphalt mix	Temp.	Test frequency (Hz)					
		2	5	8	10	20	30
FR ACO 11 S_2	15°C	6,273	7,191	7,650	8,874	10,175	11,246
	20°C	4,045	4,897	5,323	6,228	7,133	7,931
ACO 11 S_2	15°C	5,644	6,430	7,145	8,431	9,646	10,432
	20°C	4,054	4,875	5,478	6,464	7,724	8,381
FR ACL 22 S	15°C	7,683	9,189	10,135	11,766	13,399	14,669
	20°C	5,265	6,515	7,302	8,517	10,179	11,137
ACL 22 S	15°C	8,134	9,506	10,199	12,036	13,680	14,759
	20°C	5,515	6,781	7,550	8,756	10,173	11,415
FR SMA 11 S	0°C	---	---	21,973	22,255	23,336	---
	15°C	10,349	12,114	12,947	13,315	---	---
	27°C	---	5,964	6,708	7,111	8,284	---
SMA 11 S	0°C	---	---	22,356	22,642	23,766	---
	15°C	10,080	11,940	12,759	13,216	---	---
	27°C	---	5,020	5,724	6,108	7,329	---
Increase of stiffness %	0°C	---	---	98.3	98.3	98.2	---
	15°C	102.7	101.5	101.5	100.7	---	---
	27°C	---	118.8	117.2	116.4	113.0	---

Table 3 Stiffness modulus determined by IT-CY test procedure

Asphalt mix	Temperature			
	0°C	15°C	27°C	40°C
ACO 11 S_1	12 330	6 600	2 070	810
FR ACO 11 S_1	13 070	7 730	2 860	1 170
Increase in stiffness %	**106,0**	**117,1**	**138,2**	**144,4**
SMA 11 S	23 040	10 750	3 740	1 090
FR SMA 11 S	24 500	12 350	5 140	1 430
Increase in stiffness %	**106,3**	**114,9**	**137,4**	**131,2**

3.3 Resistance against Permanent Deformation

Resistance against permanent deformation was determined according to standard CSN EN 12697-22+A1 (Wheel tracking test) which describes the test methods for determining asphalt mixture susceptibility to permanent deformation under loads; this can only be applied to mixtures with maximum grain size of 32 mm. The asphalt mixture resistance to permanent deformation is assessed by the depth of the track created and its increments caused by repetitive driving of the test wheel under constant temperature (for testing within this paper, the temperature was 50°C - method B, small device, in air). The test assesses two parameters, WTS_{AIR} which is defined as increase of depth of the wheel track per 1,000 test cycles, and PRD_{AIR} which is the relative depth of the wheel track after 10,000 test tracks in proportion to the test specimen thickness. The requirement for top quality mixtures is WTS_{AIR} less than 0.07 and PRD_{AIR} less than 5 %.

Table 4 Resulting characteristics of wheel tracking test

Asphalt mix	WTS_{AIR} (mm/10^3 cycles)	PRD_{AIR} (%)
FR ACO 11 S_1	0,026	3,93
ACO 11 S_1	0,032	5,15
FR ACO 11 S_2	0,024	5,98
ACO 11 S_2	0,050	5,48
FR ACL 22 S	0,050	2,91
ACL 22 S	0,024	2,05
FR SMA 11 S	0,019	3,00
SMA 11 S	0,023	3,59

All basic mixtures met the requirements for top quality mixtures, marked by "S" in the Czech Republic. In cases where the effect of application of fibers in the mixture was assessed, the resistance to permanent deformation improved in both AC and SMA mixtures. The improvement ranged from 20 % to 30 %. In relation to stage two, where mixtures with basic bitumen 50/70 and FORTA FI fiber were compared to mixtures where PmBs were used, it must be noted that the mixtures with the fibers failed to achieve comparable results. Nevertheless, the results obtained are satisfactory as the mixtures met the requirements for top quality mixtures. The mixtures with fibers were not optimized in any manner; they were only produced by replacing PmBs with 50/70 bitumen and fibers.

3.4 Resistance against Crack Propagation

The resistance against crack propagation was determined according to standard CSN EN 12697-44 which will soon be applicable. The resistance is determined on semi-cylindrical specimens with a crack in the middle, see fig. 5; during the measurement the specimen is deflected in three points to induce tensile stress in the centre of the bottom face of the specimen. The specimen is loaded by a deformation constantly increased by 5 mm per minute. The load is increased until the maximum value, F_{max}, which is directly related to the specimen’s resistance to fracture.

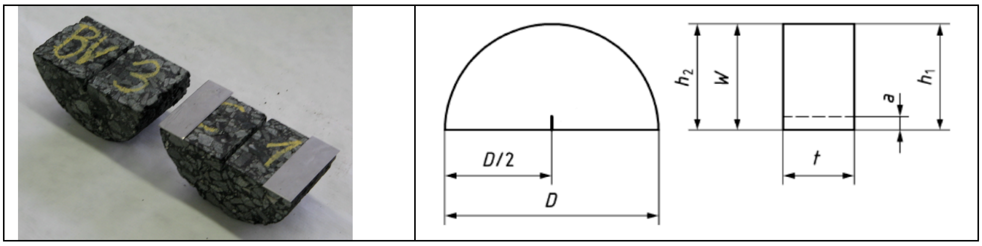

Figure 5 Semi-cylindrical test specimens, including specific dimensions of the specimen

With semi-cylindrical specimens, characteristic dimensions are measures, see fig. 5. The diameter of the specimen *D*, heights of the specimen on each side h_1 and h_2, average height *W*, thickness of specimen t_1, t_2 and t_3, depth of groove *a* in the centre of the specimen.

When the dimensions have been measured the specimen is put in a climatic chamber where the specimens are cooled/preheated to the test temperature for 4 hours. The standard does not specify a fixed test temperature; it only mentions the most common temperature as 0°C. Two test temperatures were chosen within the framework of this paper; 0 and 40°C. The preheated specimen is taken out, tapes are attached with glue (see fig. 5) and positioned between cylindrical supports and the load tape. When it has been made sure that the specimen is in the centre of the test device the specimen is loaded by constant deformation increment of 5.0 mm per minute. When the maximum load (specimen is deformed) the specimen is left to bear the load for a certain additional time period to obtain data on the residual strength of the specimen. The force and vertical shift are recorded during the entire test.

The strain ε_{max} under maximum force, maximum tension under deformation σ_{max}, which applies to the bottom face of the specimen, geometric factor f(a/W), fracture toughness K_{Ic} are calculated for each specimen.

The test results are given in table 5 and demonstrate a positive effect of reinforcing the mixture with fibers on the test results. However, as there is no long-term experience with the method we cannot present an unambiguous interpretation of the results. The work diagram shows a difference between the behaviors of the reinforced and non-reinforced specimens. The work necessary to fracture a specimen after the collapse is bigger in the case of reinforcement. The results also confirmed the fact that the strength characteristics are not too suitable to describe SMA mixtures (analogously to the Marshall stability characteristic or indirect tensile strength results). Despite the tougher binder in the case of SMA mixtures, the measurements showed lower strengths and other test characteristics

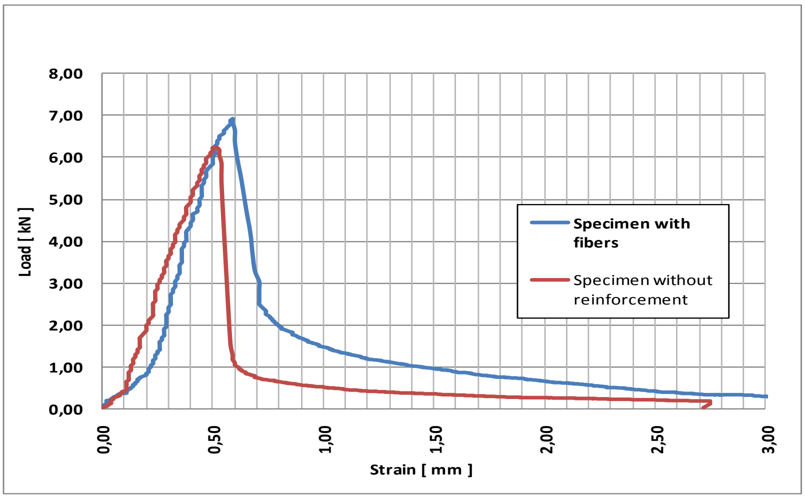

Figure 6 Stress-strain diagram for reinforced and non-reinforced specimen

Table 5 Results of testing resistance against crack propagation

Asphalt mix	Maximum loading (kN)	Tensile bending strength (MPa)	Fracture toughness ($N/mm^{3/2}$)
ACO 11 + _3	8,5	6,3	47,10
FR ACO 11 + _3	9,7	7,2	53,75
SMA 11 S	6,2	5,3	37,35
FR SMA 11 S	6,4	5,5	39,41

3.5 Fatigue

Fatigue testing has been executed in the NAT apparatus using indirect tensile test on cylindrical specimens and substandard conditions, i.e. only 8 specimens with dimensions of 101.5 mm diameter and 30 mm height were tested by applying three different loading levels. Results gained for ACO 11 S mix have therefore been considered with caution. The absolute values measured do not have full information value with respect to the measurement methodology applied; however, the comparison of fiber-containing mixture with fiber-free mixture is representative.

Based on the fatigue test results, the mixture tested is assessed to be resistant against the effects of repetitive tensile stress. The test simulates tensile stress induced in the structural layers of the pavement by moving loads. The test is based on repetitive transfer of the pressure load in the level of vertical section of the specimen which induces repetitive transverse tensile stress perpendicular to the direction of the load. The course of the specimen's vertical deformation until fracture is measured within the test.

The result of the fatigue test is the development of vertical deformation of the specimen until fracture in relation to load cycles. As a standard, the values obtained are assessed in the Wöhler diagram which gives the relationship between the effect of the load (horizontal load) and life (load cycle quantity). The relationship usually consists of a line in logarithmic scale; its slope is assumed to give a good characteristic of the fatigue life of the asphalt mixture.

The design values in TP170 require ε_6 for AC 135 (x10^6), B=5 or 115 AC (x10^6), B=5 based on the binder used and layer in the pavement structure. In described case, asphalt mixtures with no fibers demonstrated slightly poorer characteristics; the mixture containing fibers had significantly higher fatigue parameters. It must be stated again that, with respect to the limited quantity of specimens, the values cannot be taken as universally valid; however, they provide a representative demonstration of the benefits of fibers in the mixture from the point of view of fatigue characteristic improvement.

Table 6 Parameters of fatigue test

Fatigue parameter	A	B	ε_6 (x10^6)
ACO 11 S_1	2,4223	3,8993	109
FR ACO 11 S_1	2,6966	5,5942	170

4. CONCLUSION

The technology of using dispersed reinforcement in asphalt mixes is not novel. We have been seeing the technology in the form of various types of fibers for quite some time now. The initial experience with mixtures of Kevlar and poly-olephin fibers brings interesting findings for the local application thereof at spots where the stiffness of the mixture and resistance to permanent deformation needs improvement, and life-time should be prolonged. The application of fibers in the mixture has no special effect on the entire technological process of production and laying. Laboratory results have shown that the compaction of the mixture is not negatively affected by the application of fibers. A better understanding of the behavior of 3D reinforcement will need a wider scope of testing, ideally in trial sections to be long-term monitored along with the traffic loads and weather conditions.

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