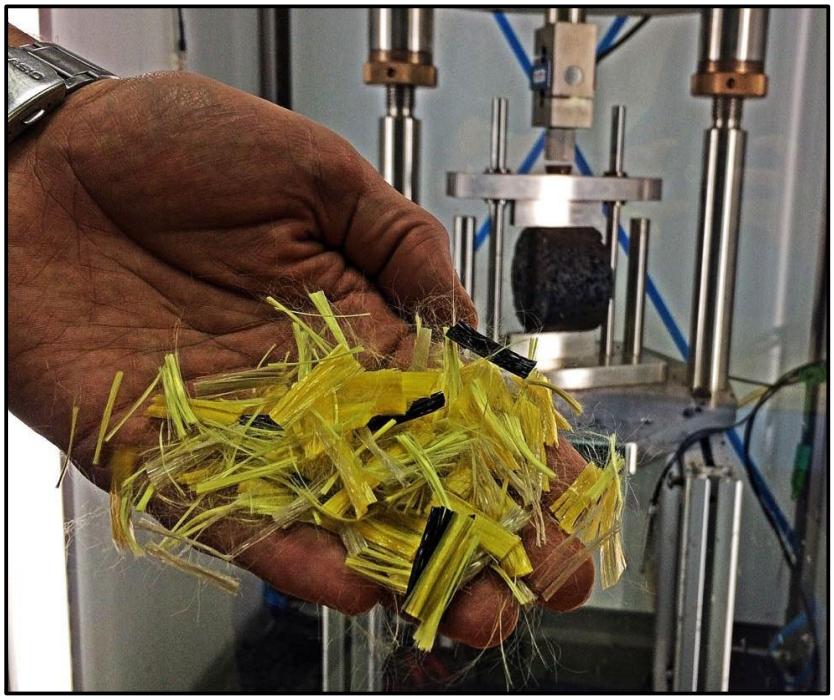
HIGHWAY INSTITUTE JSC, BELGRADE
Institute for Building Materials
Laboratory for Asphalt, Hydrocarbon Binders and Waterproofing

R E P O R T

ON APPLICATION POSSIBILITIES OF "FORTA-FI®" FIBRES FOR MANUFACTURING OF ASPHALT MIXTURES

Ordering party: **"OPTICUS" DOO BEOGRAD**



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G E N E R A L D A T A:

Subject: **REPORT ON APPLICATION POSSIBILITY OF "FORTA-FI®" FIBRES FOR MANUFACTURING OF ASPHALT MIXTURES**

Ordering party: **"OPTICUS" DOO BEOGRAD**

Order: **from 25th Jan 2018 (Our No. 50-471 from 25th Jan 2018)**

Specimen receipt register: No. 50-251 from 19th Jan 2017

Contractor: **HIGHWAY INSTITUTE JSC, BELGRADE, Peka Dapčevića Blvd 45**
Institute for Building Materials
Laboratory for Asphalt, Hydrocarbon Binders and Waterproofing

Date: **March 2018**

HEAD OF LABORATORY — DIRECTOR OF INSTITUTE

Imre Pap, PhD, B.Sc.Tech. — **Ivica Vesić, B.Sc.C.E.**

1. INTRODUCTION

At the request of company “OPTICUS” DOO BEOGRAD, a programme was prepared (Our No. 50-8272 from the 15th Nov 2017) for testing of the application possibility of "FORTA-FI®" fibres for manufacturing of asphalt mixtures. The programme was accepted on the 25th Jan 2018 (Our No. 50-471).

The effect of "FORTA-FI®" fibre addition to the properties of asphalt mixture has been tested on the standard asphalt mixture AB 11s with road grade bitumen BIT 60 (B 50/70) and in accordance with the following programme:

1. Design of optimum composition and manufacturing of asphalt mixtures of the asphalt concrete type for wearing course with and without addition of "FORTA-FI®" fibres, and preparation of specimens for laboratory testing

2. Testing of standard physical-mechanical properties of asphalt mixtures with and without addition of "FORTA-FI®" fibres according to SRPS U.E4.014,

3. Testing of asphalt resistance to ruts (wheel tracking tests) with and without addition of "FORTA-FI®" fibres on specimens prepared in the laboratory, and in accordance with SRPS EN 12697-22:2012,

4. Determination of asphalt mixtures cohesive properties with and without addition of "FORTA-FI®" fibres from the test of indirect tension and fall of tensile strength before and after exposure to water, according to SRPS EN 12697-12:2012 and SRPS EN 12697-23:2012,

5. Determination of dynamic stiffness module from the test of indirect tension of asphalt mixtures with and without addition of "FORTA-FI®" fibres, and according to SRPS EN 12697-26:2012,

6. Determination of resistance to permanent deformations from the test of permanent deformation under cyclic pressure of asphalt mixtures with and without addition of "FORTA-FI®" fibres according to SRPS EN 12697-25:2012,

7. Determination of resistance to fatigue from the test of indirect tension of asphalt mixtures with and without addition of "FORTA-FI®" fibres, according to SRPS EN 12697-24:2013,

8. Processing of test results and preparation of the Report with assessment regarding the application possibility of "FORTA-FI®" fibres as addition for asphalt mixtures.

2. GENERAL PART

The mixture of "FORTA-FI®" fibres is based on aramid and polyolefin. Aramid is of yellow, and polyolefin is of grey colour. During mixing with hot asphalt polyolefin dissolves in bitumen, and aramid fibres disperse in the mineral mixture thus forming a three-dimensional structure in the asphalt. The mixture of "FORTA-FI®" fibres is added to the asphalt mixture in the quantity of 0.05 %(mm/mm), aimed at enhancing the physical-mechanical and dynamic properties of asphalt mixtures.

Addition of "FORTA-FI®" fibres increases the stiffness module, resistance to ruts (wheels tracking), resistance to fatigue, indirect tensile strength, and fall of indirect tensile strength of the asphalt mixture in comparison to a mixture with standard bitumen BIT 60 (B 50/70). Higher stiffness module increases the bearing capacity of the pavement, which enables decrease in thickness of the asphalt layer and thus in the construction costs.

Technology of manufacturing and installation of asphalt is the same and does not differ from the classical manufacturing of asphalt pavement.

All tests were performed on the asphalt mixture of asphalt-concrete type AB-11s, used for construction of the wearing surface on highways and roads with heavy-duty traffic load.

3. EXPERIMENTAL PART

All the component materials of the asphalt mixture (filler, crushed sand, aggregate, bitumen) – have been tested in accordance with the relevant standards. The following components were used for manufacturing of asphalt mixtures AB11s: filler with carbonate composition, crushed sand and aggregate with silicate composition, which corresponds to the requirements of the standard SRPS U.E4.014:90 for heavy-duty traffic load. Road bitumen of type B 50/70 was used as a binder as well as 0.05% "FORTA-FI®" in relation to the asphalt mixture. Testing of asphalt mixtures was performed on Marshall test specimens, prepared in accordance with SRPS EN 12697-35:2012, and on asphalt slabs made with a roller compactor in accordance with SRPS EN 12697-33:2012. The compacting temperature of asphalt mixture specimens with binder B 50/70 and with fibres was 150 ± 3°C.

3.1 Designing of composition and testing of physical-mechanical properties of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres

The following basic materials were used for testing of asphalt mixtures for wearing surface AB 11s:

- Filler “Pro Kalk” – Donje Crniljevo
- Crushed sand 0/2mm, “Mrčići” – Divčibare
- Stone chippings 2/4, 4/8 and 8/11.2 mm, Mrčići – Divčibare
- Bitumen binder BIT 60 (B 50/70) – Pančevo
- Fibres "FORTA-FI®"

3.1.1 Composition of mineral mixtures AB 11s

Mineral mixture for AB-11s was designed from crushed sand 0/2 mm, “Mrčići” – Divčibare, crushed stone aggregate 2/4, 4/8 and 8/11.2 mm “Mrčići” – Divčibare with addition of filler “Pro Kalk” – Donje Crniljevo.

Table 1 and Figure 1 presents the granulometric composition of the mineral mixture AB 11s.

Table 1. Granulometric composition of the mineral mixture AB 11s, passes in % (m/m)

	0.09 mm	0.25 mm	0.71 mm	2.0 mm	4.0 mm	8.0 mm	11.2 mm	16.0 mm	22.4 mm
Design.	**9.0**	**13.3**	**20.9**	**40.5**	**56.9**	**80.5**	**98.6**	**100**	
SRPS U.E4.014:90	3 - 11	8 - 18	16 - 30	31 - 48	49 - 65	75 - 87	97 - 100	100	
Tol.p.	± 1.5	± 2.0	± 3.0	± 4.0	± 4.0	± 4.0	-	-	

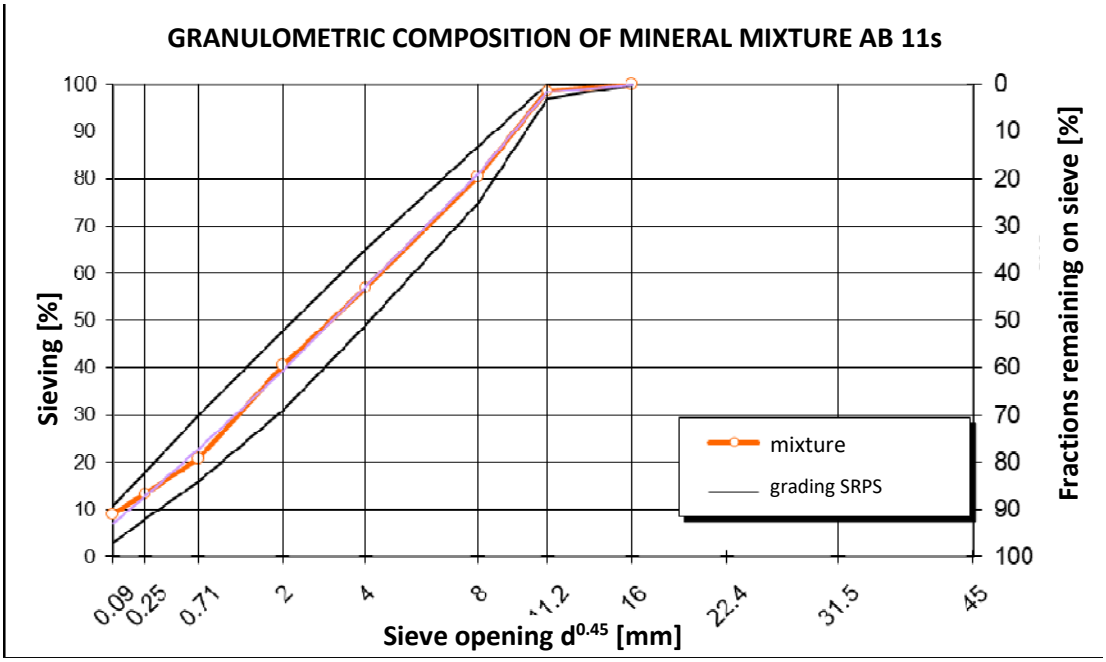

Figure 1. Diagram of mineral mixture AB 11s granulometric composition

3.1.2 Composition of asphalt mixtures AB 11s

Optimum composition of asphalt mixture AB 11s was determined by Marshall's method and is presented in Table 2 with binder BIT 60 (B 50/70), and with the addition of 0.05% to asphalt mixture, of "FORTA-FI®" fibres.

Table *2. Composition of standard asphalt mixture AB 11s with 5.6% (m/m) B 50/70*

Name of basic materials	Mineral mixture	Asphalt mixture
Filler "Pro Kalk" – Donje Crniljevo	8.5	8.0
0/2 mm "Mrčići" - Divčibare	33.5	31.6
2/4 mm "Mrčići" - Divčibare	11.0	10.4
4/8 mm "Mrčići" - Divčibare	28.0	26.4
8/11.2 mm "Mrčići" - Divčibare	19.0	18.0
Binder BIT 60 (B 50/70) Pančevo	-	5.6
"FORTA-FI®" fibres		0.05
T O T A L:	100.0	100.0

Temperature of Marshall asphalt mixture specimen compaction was 150 ± 3 °C with 2x50 strokes for standard mixture AB 11s with BIT 60 (B 50/70), and for asphalt mixture with addition of fibres.

Optimum content of bitumen in the standard asphalt mixture AB 11s and in the asphalt mixture with addition of "FORTA-FI®" fibres is 5.6 % (m/m).

3.1.3 *Physical-mechanical testing of asphalt mixtures AB 11s*

Determination of physical-mechanical properties of asphalt mixture was performed according to standards SRPS EN 12697-34:2013, SRPS EN 12697-23:2012, SRPS EN 12697-12:2012, SRPS U.E4.014:90, SRPS U.M8.093:67, SRPS U.M8.081:67 and SRPS U.M8.082:67.

Comparative results of testing of physical-mechanical properties of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres are given in Table 3.

Table 3. Physical-mechanical properties of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres

PROPERTIES	METHOD	TESTING RESULTS		CRITERIA PER SRPS U.E4.014:90
		AB 11s	AB 11s + "FORTA-FI®"	
Stability at 60°C, (kN)	SRPS EN 12697-34: 2013	10.3	10.8	> 8.0
Flow at 60°C, (mm)		4.7	4.7	-
Stability and flow ratio at 60° C, (kN/mm)		2.2	2.3	> 2.2
Voids in asphalt specimen, % (v/v)	SRPS U.E4.014:90 т.13.5.3	5.0	5.0	4.5 – 5.5
Voids in mineral mixture filled with binder, % (v/v)	SRPS U.E4.014:90 т.13.5.5	72.7	73.0	66 - 78
Voids in mineral mixture, % (v/v)	SRPS U.M8.093:67	18.4	18.5	-
Bulk density of asphalt specimen, (kg/m3)	SRPS U.M8.081:67	2439	2454	-
Apparent bulk density of asphalt mixture, (kg/m3)	SRPS U.M8.082:67	2568	2584	-
Optimum binder content, (%)	SRPS U.E4.014:90	5.6	5.6	-

The test results show that the asphalt mixture with addition of "FORTA-FI®" fibres has higher stability and stability and flow ratio by Marshall for approximately same volume properties of the asphalt mixture.

3.2 Dynamic testing of asphalt mixture specimens

3.2.1 Determination of indirect tensile stiffness module (E) (ITSM – Indirect Tensile Stiffness Modulus Test)*

Dynamic stiffness module of asphalt mixture (E*) is determined on Marshall's specimens from the indirect tensile test in accordance with the standard SRPS EN 12697-26:2012.

The test was performed under the following conditions:

- temperature: 20 ± 0.5 °C
- loading rise-time: 124 ± 4 ms
- pulse repetition: 3.0 ± 0.1s
- number of load cycles: 5

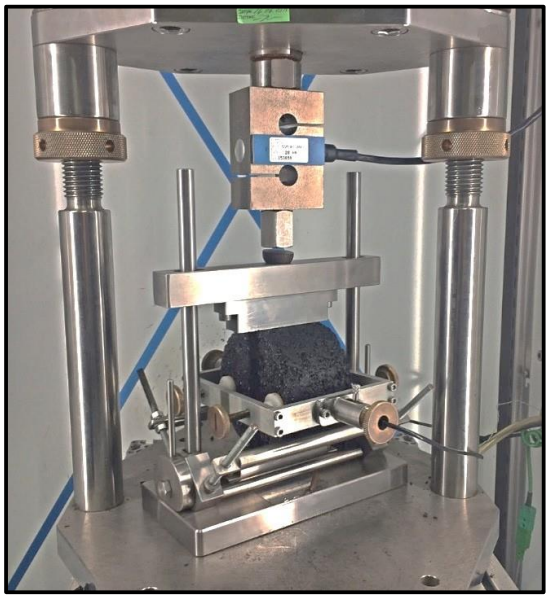

Figure 2. Test of determination of dynamic stiffness module (E)*

Table 4 gives the results of testing of dynamic stiffness module (E*) of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres.

Table 4. Dynamic stiffness module (E) of asph. mixture AB 11s with and without "FORTA-FI®"*

Mixture type	Dynamic stiffness module E* (MPa)
	MEASURED
AB 11s	5840
AB 11s +"FORTA-FI®"	6777

The testing results show that the addition of "FORTA-FI®" fibres increases the stiffness module of the asphalt mixture by 16% in comparison to the basic asphalt mixture.

3.2.2 Determination of resistance to fatigue (ITFT-Indirect Tensile Fatigue Test)

Resistance to fatigue of the asphalt mixture is determined by indirect tensile fatigue test on Marshall's specimens with diameter of Ø100 mm (Figure 3), and in accordance with the standard SRPS EN 12697-24:2013.

The test was performed under the following conditions: - temperature: 20 ± 0.5°C
- Loading rise-time: 124 ms.

Diagram on Figure 4 gives the results of measurements of resistance to fatigue of cylindrical asphalt specimens from the ITFT – dependence of micro-expansion under tension ε_x ($50x10^{-6}$ mm/mm) on the number of loading cycles to fatigue at 20°C for AB 11s with and without addition of "FORTA-FI®" fibres.

Figure 3. Test for determination of resistance to fatigue

Table 5 and diagram on Figure 4 give the results of testing of resistance to fatigue of cylindrical asphalt specimens from the ITFT – dependence of micro-expansion under tension ε_x ($50x10^{-6}$ mm/mm) on the number of loading cycles to fatigue at 20°C for AB 11s with and without addition of "FORTA-FI®" fibres.

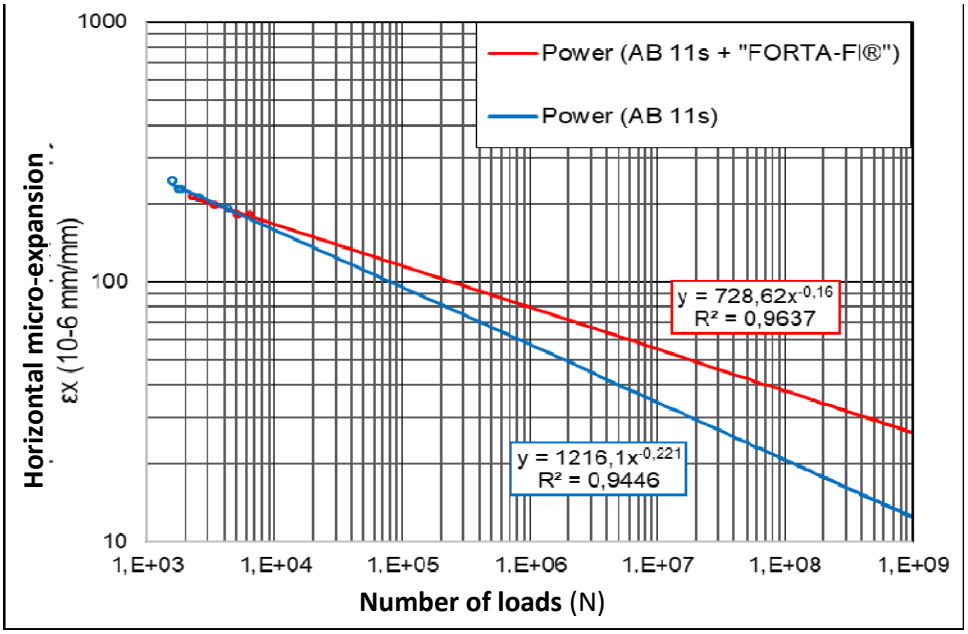

Figure 4. Diagram on resistance to fatigue of asphalt mixture AB 11s with and without "FORTA-FI®"

Table 5. *Resistance to fatigue of asphalt mixture AB 11s with and without "FORTA-FI®"* addition

Mixture type	Number of loading cycles to fatigue (N x 10^6) in horizontal micro-expansion of 50x10^{-6} mm/mm
	MEASURED
AB 11s	1.868
AB 11s +"FORTA-FI®"	18.710

The results of resistance to fatigue testing of asphalt specimens, show that the asphalt mixture AB 11s with addition of "FORTA-FI®" fibres has a smaller slope of fatigue curve and by 10 times higher resistance to fatigue from the standard asphalt mixture without fibres.

3.2.3 Determination of resistance to ruts (WTT- Wheel Tracking Test)

Resistance to ruts of the asphalt mixture is determined based on the resistance test to permanent deformation by wheel tracking method on the slabs prepared in the laboratory and with dimensions of 320 x 260 x 50 mm.

The test was performed in accordance with the standard SRPS EN 12697-22:2012. Method B in the air, Small size wheel device under the following conditions:

- Conditioning: 360min.
- testing temperature: 60 ± 0.5°C
- number of cycles/repetitions: 10000/20000

Diagram on Figure 5 gives the results of measurements in resistance to ruts of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres on the slabs with dimensions 320x260x50 mm, prepared in accordance with SRPS EN 12697-33:2012.

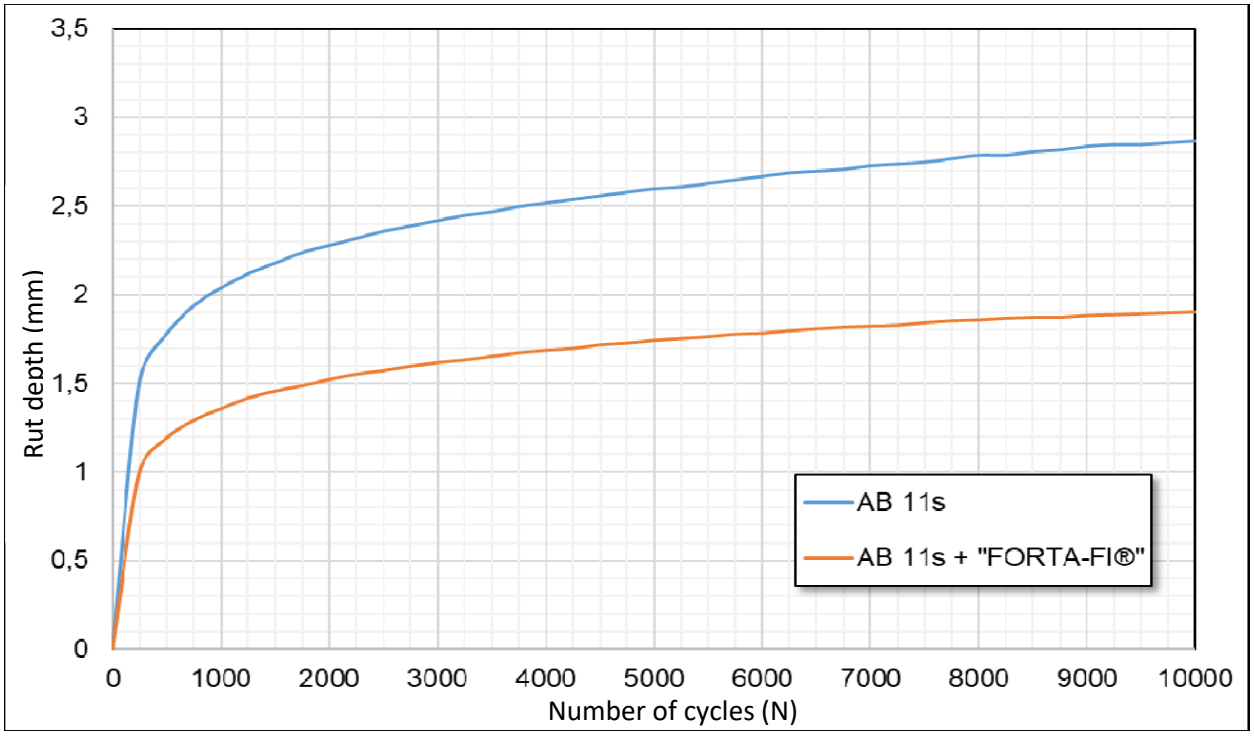

Figure 5. Diagram of resistance to ruts of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres.

Table 6 shows the results of testing of resistance to ruts of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres.

Table *6. Resistance to ruts of asphalt mixtures AB 11s with and without addition of "FORTA-FI®" fibres*

PROPERTY	TESTING RESULTS		CRITERIA PER SRPS 13108-1
	AB 11s	AB 11s + "FORTA-FI®"	
Specimen thickness, (mm)	50.0	50.0	-
Rut depth, RD_{air}, (mm)	2.58	1.90	-
Proportional rut depth, PRD_{air}, (%)	5.16	3.80	max.5.0 (max.7.5)
Curve gradient WTS_{AIR}, mm/10^3 loading cycles	0.055	0.032	max. 0.03 (max. 0.05)

Figure 6 shows the asphalt mixture AB 11s specimen with and without addition of "FORTA-FI®" fibres upon performed testing of resistance to permanent deformation by the wheel method.

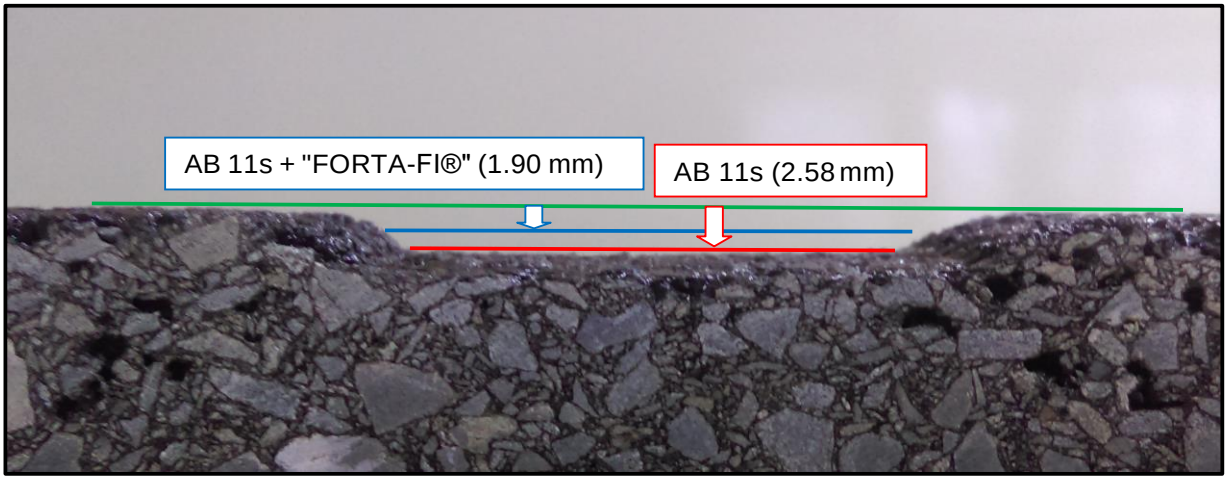

Figure 6. Specimen after the testing of resistance to ruts

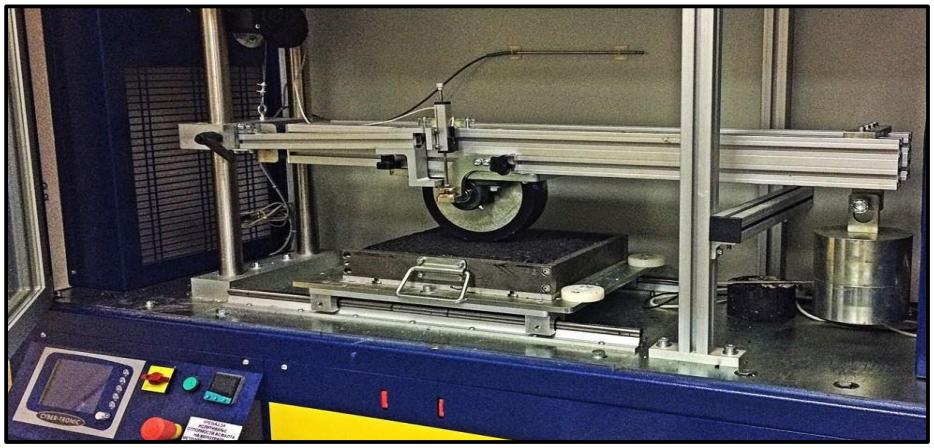

Figure 7. Devices and specimen during the rut testing

3.2.4 Permanent deformation under cyclical pressure (RLA - Repeated Load Axial)

Determination of permanent deformation under cyclical pressure of asphalt mixture has been performed on Marshall's specimens with diameter of Ø100 mm, and in accordance with the standard SRPS EN 12697-25:2012, method B (Three-axial Compression Test), Figure 8.

The testing was performed under the following circumstances:
- temperature: 40 ± 0.5°C,
- lateral pressure: 50 kPa;
- axial pressure: 100 kPa;
- number of cycles: 3600.

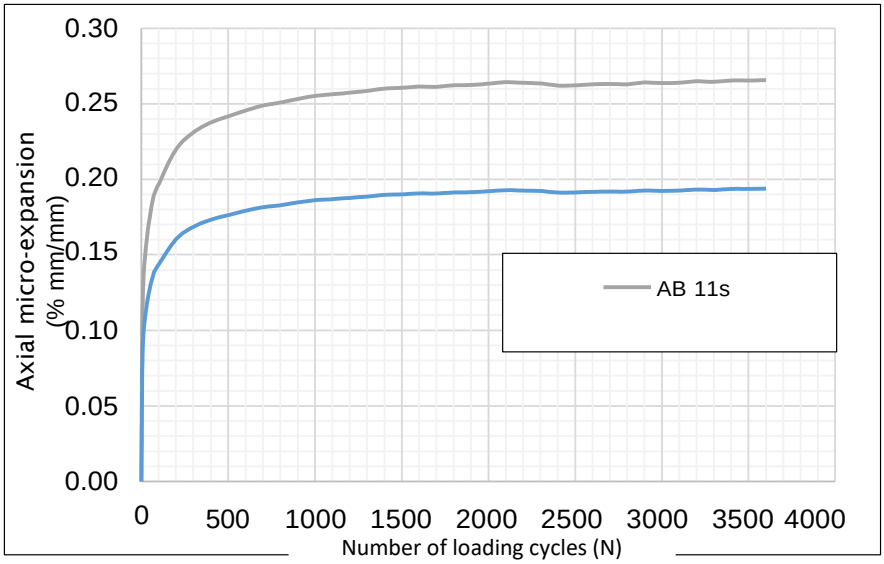

Figure 8. Diagram of axial micro-expansion under cyclical pressure

Table *7. Resistance to ruts in asphalt mixture AB 11s with and without addition of "FORTA-FI®" fibres*

Properties	Method	Mixture	
		AB 11s	AB 11s + "FORTA-FI®"
Axial permanent expansion (% mm/mm)	SRPS EN 12697-25: 2012	0.2656	0.1938

The testing results given in Table 7 show that the asphalt mixture AB 11s with the addition of fibres has smaller axial micro-expansion (% mm/mm) by 27%. Application of fibres has positive impact on permanent deformations, which has been proven by the rut test and test of cyclical pressure in prevented lateral deformations.

3.2.5 ITSR-Indirect Tensile Strength Ratio

Determination of indirect tensile strength of asphalt mixture was performed on Marshall's specimens with diameter of Ø100 mm (Figure 8), and in accordance with the standard SRPS EN 12697-23:2012, Method A.

The testing was performed under the following conditions:
- temperature: 25 ± 0.5°C,
- load-rise acceleration: (50 ± 2) mm/min,
- samples treated in water bath at 40 ± 0.5°C in the time period of 72 h.

Figure 9. Indirect tensile strength test

Table 8. Indirect tensile strength ratio of samples of asphalt mixture AB 11s with and without addition of "FORTA-FI®"

Properties	Method	Mixture	
		AB 11s	AB 11s + "FORTA-FI®"
Indirect tensile strength of dry conditioned specimens at 25°C (kPa)	SRPS EN 12697-23:2012	1228.3	1349.4
Indirect tensile strength in water saturated condition after water immersion for 72 h at 40ºC, (κPa)	SRPS EN 12697-23:2012	996.2	1111.9
Indirect tensile strength ratio at 25ºC (%)	SRPS EN 12697-12:2012	18.9	17.6

Figure 10. Failure type of specimen of asphalt mixture AB 11s with and without addition of "FORTA-FI®"

The testing results show that the asphalt mixture AB 11s with the addition of "FORTA-FI®" fibres has higher indirect tensile strength (ITS) by 10%. Besides the indirect tensile strength, application of fibres has positive impact on the ITS ratio. All samples are of mixed failure as can be concluded on Figure 10, with illustration of mixed failure from the standard SRPS EN 12697-12:2012.

4. ANALYSIS OF TESTING RESULTS

Asphalt mixture for wearing surface AB 11s with addition of 0.05% of "FORTA-FI®" fibres with aramids and polyolefin, has higher stiffness and resistance to permanent deformations (resistance to ruts and cyclical pressure), as well as higher resistance to fatigue and smaller impact of water on cohesion, which results from higher tensile strength of aramid fibres.

Dynamic stiffness module represents a ratio between amplitudes of stress and deformations as well as a function of loading frequency and temperature. Upon determination of the dynamic stiffness module, the conclusion is that application of fibres provides a stiffer asphalt mixture. Stiffness module of the asphalt mixture with B 50/70 increased from 5840 MPa to 6777 MPa in asphalt mixtures with the addition of "FORTA-FI®" fibres.

Resistance of the asphalt mixture to permanent deformations was determined through the rut test. Appearance of ruts may be caused by settling and/or highly plastic deformation in the carriageway part exposed to wheels' crossing. The value of rut depth in asphalt mixture with addition of fibres is 1.90 mm (3.80%), while the rut depth of the asphalt mixture with B 50/70 is 2.58 mm (5.16%). Gradient of the deformation curve of dependency – rut depth from number of load cycles – wheel crossing, in asphalt mixture with addition of "FORTA-FI®" fibres is 0.032, while in the asphalt mixture without fibres it is 0.055, which indicates higher resistance to appearance of ruts.

Resistance to permanent deformations was also determined in the test with cyclical stress at prevented lateral deformation, at axial stress of 100 kPa and lateral pressure of 50 kPa. Asphalt mixture with addition of "FORTA-FI®" fibres has axial micro-expansion of 0.1938 (% mm/mm), while the asphalt mixture without addition of fibres had 0.2656 (% mm/mm). This test showed that the asphalt mixture with addition of "FORTA-FI®" fibres has higher resistance to permanent deformations and therefore higher bearing capacity and durability of the pavement as also shown by the ruts testing.

Resistance of the asphalt mixture to fatigue was determined by indirect tensile fatigue test (ITFT) on cylindrical specimens. Based on the testing results, a function was formed where it is possible to define the resistance of asphalt mixture to fatigue. As a criterion of resistance to fatigue a value of number of cycles was adopted in horizontal micro-expansion $\varepsilon_x = 50x10^{-6}$ mm/mm. The asphalt mixture AB 11s ($\varepsilon_x = 1216.1*N^{-0.221}$) has a bigger curve gradient which results in the number of cycles of $1.868*10^6$ in horizontal expansion of $\varepsilon_x = 50x10^{-6}$ mm/mm. Therefore, it is less resistant to fatigue relative to the asphalt mixture AB 11s with addition of "FORTA-FI®" fibres ($\varepsilon_x=728.62*N^{-0.160}$), which produces horizontal micro-expansion of $\varepsilon_x = 50x10^{-6}$ mm/mm in $18.710*10^6$ number of

cycles. With this test, it was established that the asphalt mixture with addition of fibres may endure a significantly higher number of vehicle crossings before appearance of initial cracks, and subsequently of progressive ones. Therefore, the asphalt mixture also has better performances related to the appearance of cracks and durability of the carriageway itself.

Indirect tensile strength in asphalt mixtures with addition of "FORTA-FI®" fibres with aramid and polyolefin is increased from 1228.34 kPa to 1349.4 kPa, while the ratio of indirect tensile strength decreased from 18.9% to 17.6% when compared to the asphalt mixture with B 50/70. This test shows that application of additives enhances the cohesive properties of asphalt mixture thus providing a more resistant mixture relative to impact of water and appearance of potholes. Mixture with a higher value of ITS ratio is less resistant to various damage to the carriageway such as appearance of cracks due to fatigue and appearance of potholes.

5. OPINION

Based on the results of laboratory testing of asphalt mixtures AB 11s, and by comparing the asphalt mixture with the standard road bitumen BIT 60 (B 50/70) and mixture with addition of "FORTA-FI®" fibres on the basis or aramid and polyolefin, it can be established that addition of 0.05% of fibres into the asphalt mixture produces the following enhancements:

- Increase of stability and stability/flow ratio according to Marshall by approximately same bulk density properties of the asphalt mixture;
- Increase of dynamic stiffness module of the asphalt mixture by 16%;
- Increase in resistance of asphalt mixture to permanent deformation (rut resistance) by 26%;
- Increase of resistance of asphalt mixture to permanent deformation (cyclical compression with prevented lateral deformation) by 27%;
- Increase of resistance to fatigue of the asphalt mixture by 10 times;
- Increase of tensile strength of asphalt mixture by 10%;
- Higher indirect tensile strength and smaller ratio of indirect tensile strength of the asphalt mixture after the impact of water.

6. FUTURE WORK RECOMMENDATIONS

Considering that testing of asphalt mixtures with addition of "FORTA-FI®" fibres, conducted in a laboratory, showed that such mixture had better properties against the standard asphalt mixture, the next phase is experimental road. This will allow the monitoring of the behaviour of the asphalt mixture with addition of fibres in the conditions of ongoing traffic and impact of climate factors. After a certain exploitation period, the properties of the installed asphalt mixture shall be re-examined, such as resistance to fatigue, resistance to appearance of ruts, water impact on cohesion, and value of dynamic stiffness module of the asphalt mixture.

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