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PREDICTION OF RUTTING FORMATION IN ASPHALT CONCRETE PAVEMENT

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Abstract. Asphalt pavement in actual circumstances is subjected to the repetitive and changing transport load. As a result of the repetitive load impact, both elastic and plastic deformations occur to the pavement. Accumulation of plastic deformations in one or several layers leads to appearance of permanent deformations or rutting. This type of deformations reduces safety and convenience of traffic. Aim of the research is investigation of the rutting dynamics on the dense graded asphalt concrete (AC) and stone mastic asphalt (SMA) mixtures. The research has been made by using the standard performance test method – wheel tracking test (WTT). Five compositions of the dense graded AC mixture and two compositions of the SMA with the conventional aggregate and one reference mixture AC 11 with the Martin steel slag aggregate have been used in the experiment. The B70/100 unmodified bitumen and SBS modified ModBit 80B has been used for the investigated mixtures. The results have shown poor strain stability of the conventional mixtures with unmodified bitumen under the heavy transport load, in comparison with the reference mixture AC 11 and SMA with modified bitumen. The results of investigating the rutting dynamics under the intensive heavy transport load have shown that the allowed rut depth 25 mm is reached already during the first year of the asphalt pavement exploitation.

Keywords: asphalt concrete (AC), modified bitumen, permanent deformation, rutting, wheel tracking test (WTT), equivalent single-axle load.

1. Introduction

Permanent deformations or rutting is the main type of damage to the AC pavement in Latvia. To eliminate it, a large section of the asphalt pavement must be renovated, which requires a lot of financial investment. In the current economic situation, this is inadmissible. In order to solve this problem, the in-depth laboratory study of deformation properties of the AC composition is required. Since 2007 the Construction Science Centre of the Riga Technical University has been participating in the *State Joint Stock Company "Latvian State Roads"* research programme "Research on Application of New Technologies", where this theme is included. Within the framework of the project, the Riga Technical University has acquired modern equipment to study the dynamics of appearance of permanent deformations. By applying the new technologies in Latvian circumstances, it is possible to timely evaluate the deformation properties of the AC mixture composition prior to its being laid on the road, by manufacturing the AC specimen close to the real circumstances and loading them on a road or a street, as well as to elaborate the AC mixture compositions, which are resistant to rut formation.

2. Aim and tasks of the research

Aim of the research is to investigate stability to strain of the AC mixture compositions applied for the surface of Latvian streets and roads under the heavy transport load by considering the local climatic circumstances.

To achieve this aim the following tasks have to be solved:

- designing of the AC mixture composition with the traditional aggregate and the modified and unmodified bitumen binder;
- investigation of the temperature and transport loads characteristic for Latvian circumstances, as the main external factors influencing formation of permanent deformation;
- determining the deformation properties of the AC specimens in the laboratory circumstances by the standard testing methods of the performance properties – the wheel tracking tests (WTT), in conformity with *LVS EN 12697-22:2007 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 22: Wheel tracking* and the cyclic pressure test (CPT), in conformity with *LVS EN 12697-25:2005 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 25: Cyclic Compression Test*;

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– investigation of the dynamics of appearance of permanent deformations with the help of the *VESYS* model.

3. Methodology

AC is considered to be a very complicated material, as concrete (Mačiulaitis *et al.* 2009). The properties of the hardened concrete depend on the selected raw materials. The results of the implemented research indicate that the most optimal solution is to use the coarse aggregate of multi-fractional or discontinuous fractional composition. The optimal composition of the concrete must be selected to ensure that the binding material is not overdosed. Analysis of the AC properties is made difficult too, due to many factors, which influence these properties, the main of these being: there is no constant load amount and its operation frequency, as well as the properties change considerably depending on the temperature and load nature. In accordance with researches of some scientists, the AC mechanical properties are the function of the load amount and temperature (Erkens 2002; Park *et al.* 2008; Sivilevičius, Šukevičius 2007). Therefore, elaboration of a mechanical model for the AC pavement, with observation of all factors influencing mechanical properties, is very complicated. There is a possibility of either to reduce a large amount of the influencing factors to several most important ones, or to perform the time consuming tests for determining other parameters and to summarise them in one model. The material models can be divided into three groups (Blab *et al.* 2004):

– rheological models;
– empiric correlation equations based on the experimental stage monitoring results;
– functional equations directly based on laboratory test results.

Plastic deformations from the repeated heavy transport load increase exponentially against the upper deformation boundary (ε = 20 mm). Growth of deformations from the cyclical load is non-linear. The internationally recognized *VESYS* method is chosen for permanent deformation prediction during experimental testing on the wheel tracking equipment, as well as on the cyclical press equipment, in accordance with the *Standart EN 12697-25* method. The *VESYS* model states that the ratio of vertical plastic strain per cycle, $\frac{d\varepsilon^p}{dN}$, to the resilient strain, ε_r, is an exponential function of the number of load cycles, N (Eq (1), Fig. 1):

$$\frac{1}{\varepsilon_r} \times \frac{\varepsilon^p}{dN} = \mu \times N^{-e}, \qquad (1)$$

where ε_r – elastic or/resilient deformation, mm; ε^p – permanent deformation, mm; N – the number of load applications, cycles; μ – parameter representing the constant of proportionality of strains; e – parameter indicating the rate of decrease.

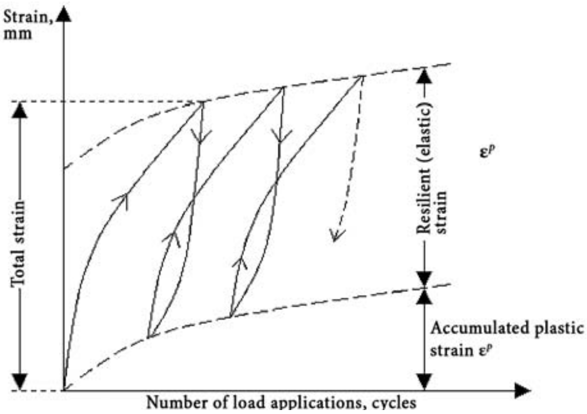

Fig. 1. Typical resilient response from repeated load applications (Park 2007)

The material parameters μ and α are determined from the following expression:

$$\mu = \frac{a \times b}{\varepsilon_r}, \qquad (2)$$

where a, b, ε_r – constants determined from testing, $\alpha = 1 - b$.

Asphalt slabs are manufactured by the roller compaction machine in accordance with the *Standard EN 12697-32:2003 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 32: Laboratory Compaction of Bituminous Mixtures by Vibratory Compactor Method*. Mechanical properties of the asphalt specimens manufactured in the laboratory are similar to those of the field compacted asphalt. For each type of asphalt, three slabs are made: two for the WTT and one for determining the resilient modulus. Thickness of the specimens corresponds to that of the field compacted asphalt layer, i.e. 40 mm. The WTT is performed in accordance with the *Standard EN 12697-22* method. The equipment in the laboratory circumstances simulates the asphalt slab specimen load, which is close to the actual heavy transport load on the asphalt pavement. Testing is performed at +50 °C – the warming up temperature of the asphalt pavement surface during the hottest summer days. The resilient modulus is determined by the indirect tensile test method in accordance with the *Standard EN 12697-26:2004 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 26: Stiffness Method*. The scheme of determining the resilient modulus is shown on Fig. 2.

4. Properties of AC and raw materials

4.1. Bitumen

Comparison of properties of the binders and evaluation of their conformity to requirements of the *Roads Specifications 2005* (Haritonovs *et al.* 2005), which are the technical specifications for construction of Latvian streets and roads, are summarised in Tables 1 and 2. The modified bitumen binder has a lower penetration and the higher softening point temperature, the larger kinematic viscosity, but the lower fragility temperature, in comparison with the conventional bitumen binder B70/100.

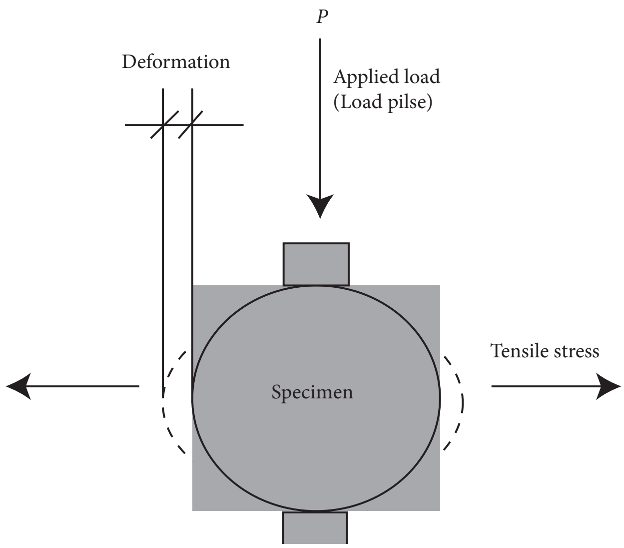

Fig. 2. Type of the cylindrical specimen (core) load (Sivapatham, Beckedahl 2005)

Table 1. Comparison of properties of the bitumen binders B70/100 and ModBit 80B

Bitumen properties	Results		Standard
	B 70/100	Modbit 80B	
Penetration 25 °C, × 0.1 mm	71	59	*LVS EN 1426*
Softening point, °C	47.70	68	*LVS EN 1427*
Paraffin wax content, %	1.10	–	*LVS EN 12606*
Kinematic viscosity 135 °C, mm^2/s	322	350	*LVS EN 12595*
Flash and fire points, °C	320	349	*LVS EN 22592*
Frass breaking point, °C	–21.20	–16	*LVS EN 12593*
Solubility in toluol, %	99.27	–	*LVS EN 12592*
Dynamic viscosity 60 °C, Pa/s	146	–	*LVS EN 12596*
Density, g/cm^3	1.0066	–	*LVS EN ISO 3838*
Resistance to hardening under the influence of heat and 135 °C			
Mass change	–0.050	0	*LVS EN 12607*
Penetration 25 °C, × 0.1 mm	72.20	40	*LVS EN 1426*
Softening point, °C	51.80	71	*LVS EN 1427*
Softening point change, °C	4.10	3.0	*LVS EN 1427*

4.2. Aggregate

The AC aggregate is selected in such a way as to include the main natural stone materials applied in manufacturing of AC in Latvia – dolomite, granite and diabase. The aggregate has its main physical and mechanical properties determined. Requirements of the *Roads Specifications 2005* regulate conformity of the aggregate categories for construction of Latvian streets and roads depending on the motor road operation conditions, for instance, traffic volume (Table 3). Distribution of the aggregate properties into categories is provided in the *Standard LVS EN 13043:2002 Aggregates for Bituminous Mixtures and Surface Treatments for Road, Airfields and Other Trafficked.*

4.3. Compositions of the asphalt concrete mixtures

Five compositions of the dense graded AC mixture and two compositions of the SMA with the traditional aggregate and one reference mixture AC 11 with the Martin steel slag aggregate have been designed (Table 4). The optimal bitumen binder composition for the AC mixtures has been determined with the help of the Marshall method.

5. Results

For the designed AC and SMA asphalts, the deformation curves – permanent deformation growth is obtained on the WTT equipment, depending on analysis of the cycles. Table 5 provides summary of the material parameters μ and α, deformation and resilient modulus for the AC specimen types used in the experiment.

The obtained results allow determining the max wheel tracking slope mm per 1000 load cycles for the AC specimens used in the research. Categories of the max wheel tracking slope mm per 1000 load (WTS_{air}) cycles are given in the *Standard EN 13108-1:2006 Bituminous Mixtures. Material Specifications. Asphalt Concrete.* According this *Standart*, the max WTS_{air} category is $WTS_{air}1$, which means that the max wheel tracking slope per 1000 cycles is 1 mm. The estimated WTS_{air} categories are provided in Table 6.

To determine the daily, weekly, monthly and annual growth of permanent deformations, the traffic volume data expressed in *ESAL* units are required, as the parameter *N* from Eq (1) is equal to the amount of *ESAL* units. *ESAL* is determined from the Eq (3):

$$ESAL = f_i \times G \times AADT \times 365 \times N \times F, \tag{3}$$

where *ESAL* – equivalent single-axle load; f_i – design line factor; *G* – growth factor; *AADT* – first year annual average daily traffic, vpd; *N* – number of axles on each vehicle; *F* – load equivalency factor for vehicle.

If accepting that the AC pavement design period on the A4 detour road (Baltezers–Saulkalne) in accordance with the project is 20 years and the annual traffic growth is 2%, the growth factor *G* will equal to:

$$G = \frac{(1+r)^n - 1}{r} = 24.30, \tag{4}$$

where $r = \frac{i}{100}$ – annual growth rate; *i* – growth rate, 2%; *n* – analysis period in years.

Table 2. Evaluation of the bitumen B 70/100 conformity to requirements of the *Standard LVS EN 12591:2000 Bitumen and Bituminous Binders – Specifications for Paving Grade Bitumens*

	Index	Standard	Requirement		Results		Evaluation
			Conventional	Modified	Conventional	Modified	
	Penetration 25 °C, × 0.1 mm	*LVS EN 1426*	70–100	50–70	71	59	Conforms
	Softening point, °C	*LVS EN 1427*	43–51	> 53	47.7	67.7	Conforms
	Paraffin wax content, %	*LVS EN 12606*	≤ 2.2	–	1.1	–	Conforms
	Frass breaking point, °C	*LVS EN 12593*	≤ –10	> –15	–21.1	–16	Conforms
	Solubility in toluol, %	*LVS EN 12592*	> 99.0	–	99.27	–	Conforms
	Kinematic viscosity 135 °C, mm^2/s	*LVS EN 12595*	> 230	–	322	–	Conforms
	Flash and fire points, °C	*LVS EN 22592*	> 230	> 235	320	349	Conforms
	Elastic reverse, %	*LVS EN 22592*	–	> 50	–	88	
Hardening *LVS EN 12607-1*	Mass change %		≤ 0.8	< 0.5	–0.050	0	Conforms
	Permanent penetration, 25 °C, × 0.1 mm	*LVS EN 1426*	> 50	> 35.4	72.2	40	Conforms
	Elastic reverse, %	*LVS EN 22592*	–	> 50	–	84	Conforms
Storage stability	Softening point change, °C	*LVS EN 13399*	–	< 5	–	1.9	Conforms
	Penetration change 25 °C, × 0.1 mm		–	< 9	–	6	Conforms

Table 3. Conformity of the coarse aggregate to the requirements of the *Roads Specifications 2005* at *AADT* > 3500 vpd

Index	Standard	Requirement		Result				Evaluation
		Dense graded AC	SMA	Lim	D	GR	MTS	
Flakiness index	*LVS EN 933-3*	≤ 15	≤ 15	11	9	12	3	Conforms
Resistance to fragmentation (Los Angeles)	*LVS EN 1097-2*	≤ 20	≤ 20	25	13	12	18	Lim does not conform
Magnesium sulphate test	*LVS EN 1367-2*	≤ 18	≤ 18	6	0.9	–	2	Conforms
Filler < 0.063 mm	*LVS EN 933-1*	≤ 2	≤ 2	2.4	1.4	1.1	0	Lim does not conform
Nordic test	LVS EN 1097-9	≤ 10	≤ 10	18	13	8	4	Lim and D does not conform

Table 4. Compositions of the dense graded AC mixture and *SMA*

AC mixture type	Aggregate fraction d-D, mass, %							Bitumen	
	11–16	5–11	8–11	5–8	2–5	0–5	Dolomite powder	B70/100	ModBit
AC 11/Lim[3)]	–	37.7	–	–	11.3	37.7[1)]	7.6	5.7	–
AC 11/Gr[4)]	–	–	51.5	20.7	51.5(30% 2–5) (70% 0–5)		3.9	4.7	–
AC 11/D[5)]	–	–	21.9	7.6	1.9	60.2	3.8	4.6	–
AC 11/Ref[6)]	–	29.8	–	–	–	42.9	6.5	6.8	–
AC 16/Lim	20.9	29.5	–	–	1.0	37.1[2)]	6.6	4.9	–
SMA 16/Gr	39.9	–	28.3	9.5	–	14.1	7.3	–	5.9
SMA 11/D	–	–	51.7	17.9	0.9	15.1	8.5	5.5	–

Note: [1)] – natural washed sand; [2)] – crushed sand; [3)] – dolomite; [4)] – granite; [5)] – diabase; [6)] – martin steel slag.

Table 5. AC deformation parameters μ and α

Material parameter	AC mixture compositions						
	AC 11/Lim	AC 11/Gr	AC 11/D	AC 11/Ref	AC 16/Lim	SMA11/D	SMA 11/D_Mod
E, MPa	11.5	33.4	32.2	115.3	55.8	68.6	164
ε^p, mm	20^{**}	13.1^{*}	14.0^{*}	11.2	16.5^{***}	7.61	3.0
ε_r, (10^{-2}) mm	58.4	43.2	31.9	13.2	32.1	23.5	3.13
μ	0.008	0.003	0.01	0.45	0.02	0.52	2.54
α	0.933	0.9830	0.977	0.470	0.825	0.446	0.201
Specimen, mm	50						

Note: $^{*)}$ ε^p= 20 mm per 1700 cycles; $^{**)}$ ε^p per 5000 cycles; $^{***)}$ ε^p per 10 000 cycles.

Table 6. Wheel tracking slope WTS_{air}

AC mixture type	WTS_{air} factual (mm/1000 load cycles)
AC 11/Lim	3.11
AC 11/Gr	2.57
AC 11/D	6.87
AC 11/Ref	0.49
AC 16/Lim	1.50
SMA 11/D	0.56
SMA 16/Gr_ModBit	0.06

There are 16% of the five-axle tracks on the A4 detour road. The amount of cars is 74%; still, their damage effect is very small, as the axle of one truck is equivalent to axles of 8 000–10 000 cars. Volume of the *AADT* on the A4 detour road is 10 000. Knowing the load equivalency factors for vehicles, *AADT* and the growth factor, the total *ESAL* is determined (Table 7).

Table 7. Total ESAL estimation parameters

Number of tracks axles	Design line factor, f_i	Growth factor, *G*	*AADT*	Load Equivalency factor for vehicle, *f*	*ESAL* in each group, $\times 10^6$	Total *ESAL* $\times 10^6$
2 axles				0.007	0.20	
3 axles				1.050	0.46	
4 axles	0.5	24.3	10 000	1.500	2.70	16.7
5 axles				1.760	12.50	
6 axles				1.820	0.80	

ESAL for the first year – $ESAL_0$ equals to:

$$ESAL_0 = \frac{\sum ESAL_i}{24.3} = 0.69 \times 10^6, \qquad (5)$$

$$Daily\_traffic = \frac{ESAL_0}{365} = 1890. \qquad (6)$$

The rut formation is assumed to take place during the period of April to September from 7^{00} till 21^{00}, when the asphalt pavement temperature can reach the high performance temperature – > 45 °C. *ESAL* for the period of April to September is 55% of the annual value, and from 7^{00} till 21^{00} it is 85% of the daily value. According *State Limited Liability Company "Latvian Environment, Geology and Meteorology Centre"*, percentage of the days with the high performance temperature during this period is 2%. The annual *ESAL* with the high pavement performance temperature is 6452.

By using Eq (2), the rut formation dynamics has been determined (Fig. 3).

6. Conclusions

In accordance with the obtained results, the maximally allowed rut depth on the asphalt pavement with the unmodified conventional bitumen is 25 mm (in Lithuania, for instance, it is 20 mm) is reached already during the first operation year of the asphalt pavement layer.

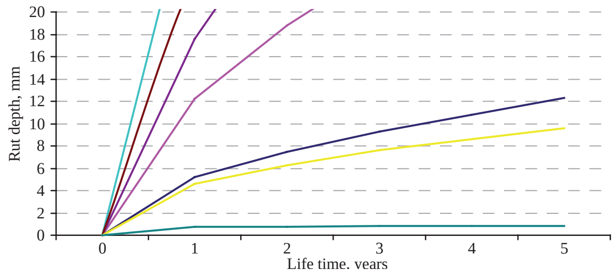

Fig. 3. Theoretical development of the rut depth on the A4 road: — AC 11/Ref; — AC 8/Lim; — AC 11/Lim; — SMA 16/Gr_mod; — AC 16/Li; — AC 11/D; — SMA 11/D

When performing the prediction research of permanent deformations, the climatic circumstances characteristic for Latvia and the transport load expressed in *ESAL* units have been taken into account.

The standard category WTS_{air} of the conventional AC mixture exceeds one.

To achieve the more reliable results, validity of the method must be performed, for instance, comparison of the results obtained experimentally with the laboratory research.

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