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RESISTANCE TO PERMANENT DEFORMATION IN BINDER CONTENT AND FILM THICKNESS VIEWPOINT

Eva REMIŠOVÁ *

* Dr.; Faculty of Civil Engineering, The University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia
E-mail address: *remisova@fstav.uniza.sk*

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Abstract

The resistance of asphalt mixtures against permanent deformation is one of important requirements that have to be verified in the design process of asphalt mixtures. In the case of asphalt concrete the European standard EN 13108-1 allows empirical (compositional recipes and requirements) or fundamental approach for testing of permanent deformation resistance. A fundamental approach specifies asphalt concrete in term of performance-based requirements linked to limited prescription of composition and constituent materials. In this design approach a compression triaxial test is used to verify resistance to permanent deformation. The presented study investigates characteristics of resistance to rutting of asphalt concrete mixtures (eight mixtures of AC11 from different producers) determined by cyclic compression test.

The basic conclusions and statements of main factors influenced resistance to rutting have been worked out from prevenient experience and experimental measuring [8]. The modified bitumen has better results of resistance to permanent deformation compared to paving grade bitumen and increasing binder content decreases the resistance to permanent deformation of mixture. But measured test results presented in following paper point out differences in resistance however the bitumen contents are relatively the same.

During detailed investigation the tested asphalt mixtures had small differences in aggregate gradation. Changes in gradation make change of aggregate specific surface and the mixture needs different bitumen content to coat aggregate particles, to bound them to each other and to make stiff material resistant to rutting. The results from measuring of resistance to permanent deformation show the relation between aggregate specific surface and bitumen film thickness and permanent deformation.

Streszczenie

Odporność mieszanki asfaltowej na trwałe deformacje jest jednym z ważnych wymogów, który musi być weryfikowany w procesie projektowania mieszanki asfaltowej. W przypadku betonu asfaltowego norma europejska EN 13108-1 dopuszcza doświadczalne (receptury składu i wymogi) lub podstawowe podejście do testów odporności na trwałe deformacje.

W fundamentalnym podejściu projektowym, badanie trójosiowego ściskania jest wykorzystane do weryfikacji odporności na trwałe deformacje. Przedstawiane studium wyznacza charakterystyki odporności na koleinowanie mieszanki betonu asfaltowego (8 mieszanek z AC11 od różnych producentów) wyznaczone przez cykliczne badanie wytrzymałościowe.

Podstawowe wnioski i zestawienie głównych czynników wpływających na odporność na koleinowanie wypływały z pracy – doświadczeń zapobiegających i wyników pomiarów w porównaniu z [8]. Zmodyfikowany bitum ma lepsze wyniki odporności na trwałe deformacje niż nawierzchniowy bitum i zwiększenie zawartości spoiwa obniża odporność mieszanki na trwałe deformacje. Jednakże pomierzone wyniki badania przedstawione w artykule zaznaczają różnice w odporności, chociaż zawartości bitumu są porównywalne.

Podczas szczegółowego badania, badana mieszanka asfaltowa miała małe różnice w uziarnieniu kruszywa. Zmiany w uziarnieniu powodują zmianę powierzchni właściwej kruszywa i mieszanka potrzebuje różną zawartość bitumu, aby otoczyć składowe kruszywa, związać je z innymi i nadać materiałowi sztywność, odporność na koleinowanie. Wyniki z pomiarów odporności na trwałe deformacje pokazują związek pomiędzy powierzchnią właściwą kruszywa i grubością powłoki bitumicznej i trwałą deformacją.

Keywords: **Asphalt mixture; Permanent deformation; Triaxial test; Creep rate; Specific surface; Bitumen film thickness.**

1. INTRODUCTION

Wheel tracking tests are usually used to verify a permanent deformation resistance of asphalts. The application of the standard EN 13108-1 for asphalt concrete allows using another test method (triaxial compression test) to verify permanent deformation resistance. A fundamental approach specifies asphalt concrete in terms of performance-based requirements linked to limited prescription of composition and constituent materials. A triaxial test is able to eliminate disadvantages of wheel tracking tests, particularly the different stress distribution in a test sample in comparison with a pavement.

Resistance to permanent deformation is one of the properties that are necessary to be tested in type testing. In general it is known that higher bitumen content negatively influenced permanent deformation resistance. But measured test results presented in the following part of paper point out differences in mixtures however the bitumen contents were relatively the same.

2. PERMANENT DEFORMATION

The permanent deformation with cracking and potholes is the most frequent distress on asphalt pavement. It represents accumulation of small number of deformations that occurs each time a load is applied. Especially with AADT increasing, heavy axle load forms stresses in asphalt layers and forms rutting characterized by downward and lateral movement of mixture. Permanent deformation (rutting) in asphalt layers develops in three stages (Fig. 1):

- *primary (initial) stage* is part of deformation, where asphalt mixture is formed and compacted by traffic (densification, volume reduction).
- *secondary (middle) stage*, it is considered to be representative of deformation behavior for the greater part of lifetime of pavement and constant rate rutting. Traffic load (horizontal and vertical) cause shear stresses in asphalts. There is a displacement of asphalt mixture and flow rutting due to shear stress.
- *tertiary (last) stage*, is characterized by accelerating rutting, excessive rapid plastic deformations considering number of load. It is typical and characteristic of asphalts unsuitable from permanent deformation point of view.

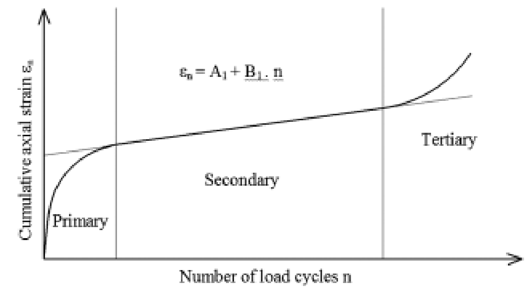

Figure 1.
The creep curve of asphalt mixtures[1]

Permanent deformation is condition of pavement failure caused by accumulation of permanent deformations by repeated axle load.

3. LABORATORY TEST METHOD

Test method B of EN 12697-25 [1] determines resistance to permanent deformation of a cylindrical specimens of asphalts. The specimen is placed between two plan parallel loading platens in triaxial chamber and is subjected to the confining pressure σ_c on which a cyclic axial pressure $\sigma_a(t)$ – sinusoidal or block-pulse loading (Fig. 2) is superposed. The requirements for

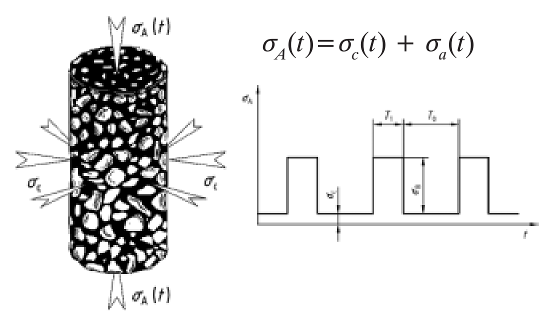

Figure 2.
The principle of sample loading by block-pulse cyclic impulses [1]

Table 1.
The test conditions for wearing course [4]

Layer	Test temperature	Confining stress	Axial stress	Frequency	Cyclic axial pressure form
wearing course	50°C	150 kPa	300 kPa	3 Hz	haversinusoidal
				1 s / 1 s	block-pulse

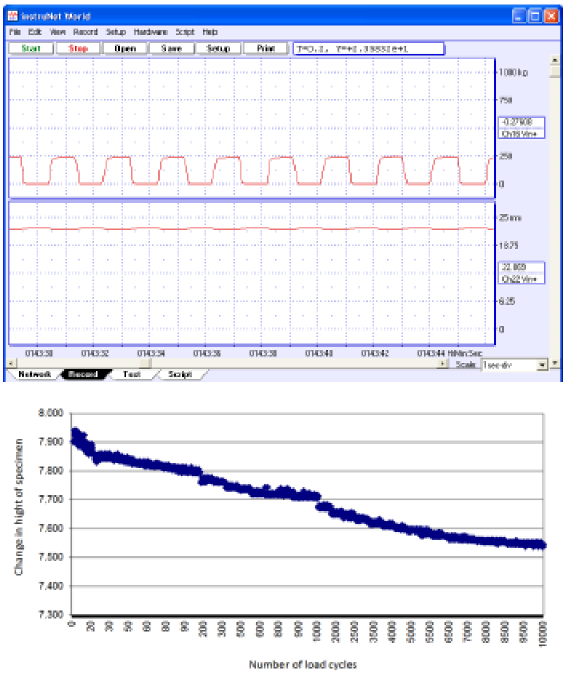

Figure 3.
Example of record of loading and record of sample height

values of pressures, frequencies and test temperatures are defined in standard EN 13108-20 type testing (Tab. 1).

During the test the changes in height of specimen are measured at specified numbers of load applications (Fig. 3). And the cumulative axial strain ε_n (permanent deformation) of test specimen is determined as a function of the number of load applications:

$$\varepsilon_n = 100.(h_0 - h_n)/h_0 \qquad (1)$$

where ε_n – is the total axial deformation of the test sample after n-loading cycles, [%],

h_0 – is the average height after preloading of the sample, [mm],

h_n – is the average height after n loading cycles, [mm].

The results are represented in a creep curve as given in Fig. 1. The resistance of permanent deformation of tested mixture is characterized by parameter f_c interpreting the creep curve. The creep rate f_c is determined in the (quasi) linear part of creep curve (stage 2 in figure 1) as the slope expressed in microstrain/loading cycle:

$$f_c = B_1 .\ 10^4 \qquad (2)$$

where B_1 is the slope of least square linear fit of the creep curve between 3 000 and 10 000 load applications and it's determined to the following formula:

$$\varepsilon_n = A_1 + B_1 .n \qquad (3)$$

where ε_n – is the total axial deformation of the test sample after n-loading cycles, [%],

A_1, B_1 – are the parameters of the linear regression,

n – is the number of load cycles.

4. EXPERIMENTAL MEASURING

Tested mixtures were asphalt concrete AC 11 with SBS polymer modified bitumen PmB 45/80-75 from batch plants. All mixtures fulfilled requirements defined in EN 13108-1 and complementary Slovak criteria [5]. The aggregate gradation and the bitumen content of 8 tested mixtures are in Tab. 2.

Table 2.
Aggregate gradation and asphalt content of tested mixtures

Sieve size, in mm	Gradation of AC 11 mixtures								
	Passing in %								
	1	2	3	4	5	6	7	8	Limits
16	100	100	100	100	100	100	100	100	100
11.2	96.8	98.2	97	97.4	97.3	97	95.5	95.6	90-100
4	46.7	52.7	46.8	48.2	55	50.6	49.8	49.7	45-67
2	32.2	34.6	33.5	33	35.9	33	33	33.5	25-50
0.50	13	15.3	16	16.1	17.4	15.8	15.9	17,1	10-33
0.063	6.5	6.8	7.9	7.5	7.1	7.2	7	8.2	4-11
Bitumen content, in %	5.74	5.66	5.7	5.7	5.7	5.7	5.7	5.7	min. 5.4

Figure 4.
Apparatus used for triaxial cyclic compression test

From previous experimental measuring [8] the assumption of better results of resistance to permanent deformation of modified bitumen versus paving grade bitumen was verified and confirmed as can be seen in Fig. 5. And in the same way increasing content of binder decreases the resistance to permanent deformation of the mixture.

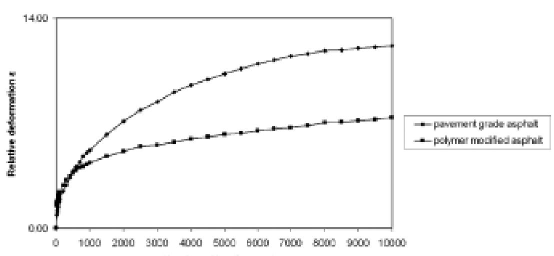

Figure 5.
The creep curve of AC11 with different binder type and same content [8]

Achieved results of the creep rate f_c of eight tested mixtures of asphalt concrete AC11 are displayed in Fig. 6. The values of a parameter fc are within the range 0.05 and 0.16 and belong to the category $f_{cmax\,0.2}$ defined in EN 13108-1. The practical experiences with carrying out the triaxial test (with the test conditions according to EN 13108-20) point to worse distinguishing of asphalts mixtures with different resistance to the permanent deformation [9, 10]. The main reason is the higher confining pressure which creates a stiff pressure cover round the test specimen restraining the shear stress.

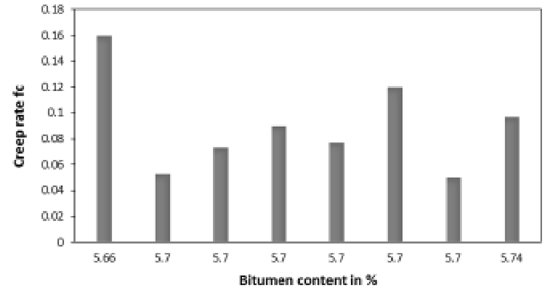

Figure 6.
Results of creep rate of tested mixtures AC11

Tested mixtures of the asphalt concrete AC 11 were with the same type of PmB bitumen and with more or less the same bitumen content (5.66 % to 5.74 %) even though different results of f_c were obtained.

During detailed investigation there were small differences in aggregate gradation. The changes in gradation make a change of aggregate specific surface (surface area) and the mixture needs different bitumen content to coat and join the aggregate particles. The thicker asphalt binder films produce mixes which were flexible and durable, while thin films produce mixes which were brittle, tended to crack and ravel excessively, retarded pavement performance and reduced its useful service life [11].

Generally the specific surface (surface area of aggregates) is determined empirically using surface area factors and gradation of aggregate. In Slovakia the aggregate surface area ε is calculated by multiplying the total mass of specified fraction expressed as a percentage passing each sieve size by appropriate factor and adding the resultants together [2]:

$$\varepsilon = 0.01.(0.174.G+0.40.g+2.30.S+15.33.s+140.f) \quad (3)$$

where: G – is the aggregate percentage retained 8 mmsieve by mass,[%],

g – is the aggregate percentage retained 4 mmsieve by mass, [%],

S – is the aggregate percentage retained 0.25 mmsieve by mass, [%],

s – is the aggregate percentage retained 0.063 mmsieve by mass, [%],

f – is the percentage passing the sieve 0.063 mm, [%].

The aggregate surface is important since it affects the amount of bitumen needed to coat the aggregate. Asphalts that have high surface area and low bitumen content are undesirable because these mixes will have a thin bitumen film on aggregate and will probably

Table 3.
Aggregate surface area and calculated bitumen film thickness of tested mixtures

Property	Mixtures AC 11							
	1	2	3	4	5	6	7	8
Surface area, in m^2/kg	10.779	11.423	12.787	12.354	12.076	11.986	11.722	13.346
Theoretical bitumen film thickness, in micron	5.649	5.252	4.727	4.893	5.005	5.043	5.157	4.529

not have enough durability. Theoretical bitumen film thickness is calculated from specific surface area and effective bitumen content in mixture according [6]:

$$T = \frac{b}{100 - b} \cdot \frac{1}{\rho_b} \cdot \frac{1}{SA} \tag{4}$$

where T – is the bitumen film thickness, [mm],

ρ_b–is the density of bitumen, [kg/m^3],

SA – is the aggregate specific surface (surface area SA=ε according [2]), [m^2/kg],

b – is the effective bitumen content in mixture, [%].

Calculated surface area and theoretical bitumen film thickness of tested mixtures are showed in Tab. 3. Comparison of reached results of permanent deformation resistance with calculated film thickness is shown in following Fig. 7.

The effective binder thickness depends on the asphalt density and the porosity of aggregate. The aggregate porosity is usually expressed by water absorption as a weight percentage of fully saturated voids to dry rock. The pore size and pore size distribution to which the binder penetrates decrease the asphalt film thickness. The tested mixes were from different batch plants without specific knowledge about used aggregate properties. To express the effective binder content it is necessary to know the effective bulk density of aggregate which wasn't determined. The requirements in Slovak Republic allow to use only aggregate with maximum 1% absorption that minimises an amount of absorbed binder in the aggregate.

From measuring of resistance to permanent deformation it can be observe that there is a relation between aggregate surface area and bitumen film thickness and permanent deformation. With higher bitumen content the film thickness increases and the aggregate particles are not close enough to interlock themselves and make strength structure and resistance to permanent deformation of mixture decreases. Exception results of mixture 1 that has greater bitumen film thickness. But it has less surface area

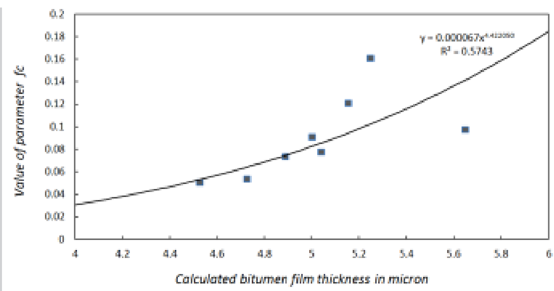

Figure 7.
Relation between theoretical bitumen film thickness and results of permanent deformation resistance of AC11

and coarse aggregate skeleton that is more resistant to rutting.

To confirm the conclusions it would be appropriate to make measurements of asphalt film thickness and to compare the calculated theoretical film thickness with the results from film thickness measuring for specific mixture.

5. CONCLUSIONS

The evaluation of the asphalt mixtures resistance to permanent deformation by cyclic triaxial test is a part of functional performance design of asphalt concrete. Triaxial test method simulates the real stress and tenseness in pavement layers. Eight mixtures of asphalt concrete (AC11) were tested for a resistance to permanent deformation and the obtained results were evaluated to next conclusions.

The permanent deformation results of all tested mixtures AC 11 belong to the category $f_{cmax\ 0.2}$. The interpretation of variance values f_c (within 0.05 and 0.16) is possible by aggregate gradation. The differences in gradation make a change of aggregate specific surface. Regard the used binder content in tested mixtures the theoretical bitumen film thickness was calculated. The mixtures with thicker film thickness had higher creep rate and thus less resistance to permanent deformation.

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