COMPARISON OF STIFFNESS MODULI USING 2-POINT AND 4-POINT BENDING TESTS

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Abstract

In this paper two different methodologies have been adopted and compared performing tests on selected asphalt concretes (AC's), called two point bending (2PB-TR) and four point bending (4PB-PB) using trapezoidal and prismatic beams respectively. Even though methodologies of these tests are known for some time interpretation of results according to the EU 12697-26 standard is rather unclear. Stiffness moduli are being compared at different temperatures, which were found unnecessary. Paper describes influence of different loadings and temperatures on selected asphalt concretes.

1 Introduction

Stiffness moduli of asphalt mixtures methods are currently under the applicable standards EN 12697-26 "Bituminous mixtures - Test methods for hot asphalt - Part 26: Stiffness and EN 13 108-20 "Bituminous mixtures - Specification for materials - Part 20: Type test." Different approaches let to the different test conditions eg. temperature, frequency and/or time of loading, list of boundary conditions are listed in Table 1.

Table 1 Test conditions for the determination of stiffness of the module according to EN 12697-26

	method of loading	temperature	loading frequency and or time
1	2PB-TR	15 °C	10 Hz
2	2PB-PR	15 °C	10 Hz
3	3PB-PR	15 °C	10 Hz
4	4PB-PR	20 °C	8 Hz
5	DTC-CY	15 °C	10 Hz
6	DT-CY nebo DT-PR	15 °C	0,02 s
7	IT-CY	20 °C	124 μs

Stiffness modulus is determined on the basis of the measured variables (strength, deformation, phase angle delay) and the known dimensions of specimens. According to the rules applicable to European standards, only one test method for each measured parameter may be used. More test methods for one exact parameter can be used only if methods give the same results.
In the Czech Republic, there are currently two laboratories only that conduct procedures of AC stiffness evaluation. Road Laboratory at Czech Technical University (CTU) in Prague, is equipped with a 4-point test (4PB-PR) and pneumatic device (IT-CY) and Road Laboratory of Brno University of Technology is equipped with a 2-point test (2PB-TR) and pneumatic device (IT-CY).

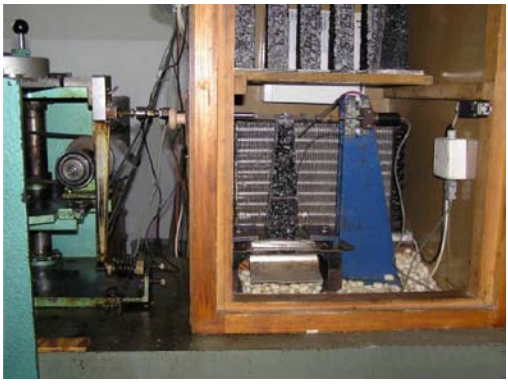
The aim of comparative tests was to evaluate stiffness modulus of selected asphalt concretes measured by 2-point and 4-point procedures. Three types of asphalt concretes were evaluated as follows: AC 11S surf, AC 16+ bin, AC 22+ base.

2 Description of test methods

2.1 Two-test 2PB-TR

According to the Czech innovated design method Code TP 170 (2001), the only methodology for thickness design is 2PB-TR for the establishment of functional modules of asphalt materials according using standard EN 12697-26 procedure. The design method considered the value of stiffness moduli provided by 2-point bending test as at 15° C and loading frequency of 10 Hz.

Figure 1 The device for measuring modules stiffness 2-point test according to EN 12697-26



2.2 4-point test 4 PB-PR

This methodology is used in countries across Europe, Australia and South Africa and especially in North America. Inputs serve as valuable data for Mechanistic-Empirical Pavement Design Guide (MEPDG).

3 Description evaluated asphalt mixtures

For testing were selected three typical asphalt concretes, in the Czech Republic, commonly used for surface, binder and base layers: AC 11 surf, AC 16 bin and AC 22 base. Selected asphalt concretes contain bitumen of penetration 50/70 for base and subbase and polymer modified bitumen (PMB) of penetration 45/80 for surface course. Following is listed in Table 2.
Czech national annex denominates two quality mix types abbreviated as:

- "S" premium mix - 2x75 Marshall blows required
- "+" conventional mix - 2x50 Marshall blows required

Table 2 Basic description of evaluated AC mixes with binder

Asphalt concrete	denomination	Bitumen
Surface course	AC 11S	PMB 45/80-50
Binder course	AC 16+	50/70
Base course	AC 22+	50/70

Figure 2 Device for measuring the stiffness of the modules 4-point test according to EN 12697-26

4 Specimen preparation

All bituminous mixtures used for evaluation were taken at mixing plant into bags, while much attention was paid to the homogeneity of samples. Subsequently, the mixture was reheated in he laboratory oven at the appropriate reference compaction temperature according to EN 12697-30 (for modified asphalt compaction temperature was chosen according to the manufacturer) and as described in EN 12397-33 were then compacted using a compactor of the mold dimensions of 300 x 400 x 50mm.
Bulk density was determined from compacted slabs in accordance to EN 12697-6 and on the basis of the maximum density of the mixture air void content was calculated. List of parameters of produced slabs are presented in Tables 3,4,5. Each layers shows different air void and binder content, which should give a wide range of existing asphalt concretes for stiffness moduli evaluation.

Table 3 Volumetric properties of AC surf 11S PMB 45/80-50

Bulk density ρ_{bssd} (kg/m³)	Maximum density ρ_{mV} (kg/m³)	Air voids V_m (%)	Binder content B (%)
2352	2449	4,0	5,6
2369		3,3	
2354		3,9	
2356		3,8	
Ø		Ø	
2358		3,7	

Table 4 Volumetric properties of AC bin 16+ 50/70

Bulk density ρ_{bssd} (kg/m³)	Maximum density ρ_{mV} (kg/m³)	Air voids V_m (%)	Binder content B (%)
2374	2491	4,7	5,2
2384		4,3	
2373		4,7	
2378		4,5	
Ø		Ø	
2377		4,5	

Table 5 Volumetric properties of AC base 22+ 50/70

Bulk density ρ_{bssd} (kg/m³)	Maximum density ρ_{mV} (kg/m³)	Air voids V_m (%)	Binder content B (%)
2379	2532	6,0	4,3
2393		5,5	
2393		5,5	
2387		5,7	
Ø		Ø	
2388		5,7	

Subsequently, using the circular saws from the compacted slabs two sets of specimens were prepared in the shapes of:

a trapezoidal specimens (lower sub-assemblies 70mm, the upper part of 35mm, thickness 50 mm)

b prismatic specimens (length 400mm, thickness 50mm, width 50mm).

5 Tests & results

Specimens were subjected to the following test, in accordance with EN 13108-20 type tests conditions (see Table 1):

a for the test 2PB-TR testing temperature of 15° C and loading frequency of 10 Hz (tests have been carried out also at additional frequencies of 5, 15, 20 and 25 Hz),

b for the 4PB-PR testing temperature of 15° C and 20° C and loading frequency of 8 Hz (tests have been carried out also at additional the frequencies of 5, 10, 20 and 30 Hz).

The following table 6 shows stiffness moduli in MPa of all measurements. Results are averages of several specimens tested at the same conditions. Graphical evaluation and comparison of the results of both tests are portrayed at figure 3.

For better understanding of 4PB-PR procedure stiffness evaluation was also conducted at temperature which corresponds to the 2PB-TR. Results are portrayed in table 7 and at following figures 4,5,6.

Table 6 Measured stiffness modules in MPa of 4-point test and 2-point test

Mixture Type	4PB-PR				
	20°C				
	5 Hz	8 Hz	10 Hz	20 Hz	30 Hz
AC 11surf PMB 45/80-50	3236	3609	4236	5132	5639
AC 16bin 50/70	3640	4018	4718	5686	6227
AC 22base 50/70	3453	3841	4514	5380	5874
Mixture Type	2PB-TR				
	15°C				
	5 Hz	10 Hz	15 Hz	20 Hz	25 Hz
AC 11surf PMB 45/80-50	5097	5740	5964	6350	6510
AC 16bin 50/70	5953	6263	6788	7212	7379
AC 22base 50/70	5444	6048	6257	6620	6776

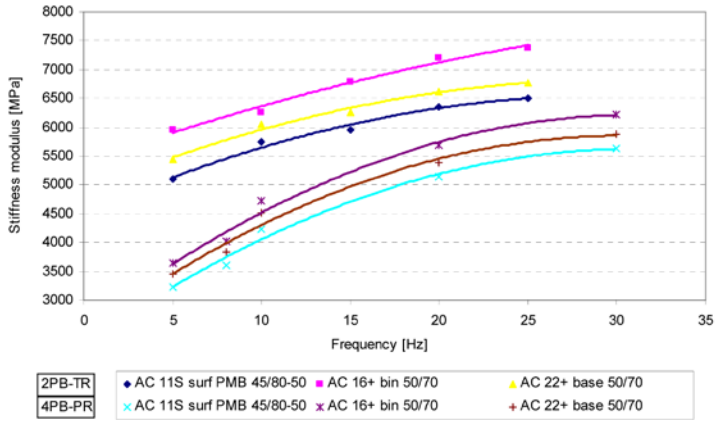


Figure 3 Results of stiffness moduli according to EN 12697-26

Table 7 Measured stiffness modules in MPa of 4-point test and 2-point test at temperature 15°C

Method	Frequency [Hz]	Mixture		
		AC 11S surf PMB 45/80-50	AC 16+ bin 50/70	AC 22+ base 50/70
2PB-TR	5	5097	5953	5444
	10	5740	6263	6048
	15	5964	6788	6257
	20	6350	7212	6620
	25	6510	7379	6776
4PB-PR	5	4740	4709	4824
	8	5129	5167	5408
	10	5907	6213	6308
	20	7041	7457	7515
	30	7571	8085	8014

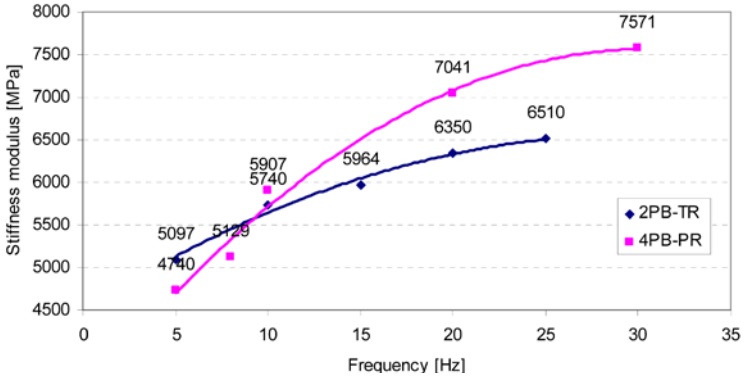


Figure 4 Results of stiffness moduli AC 11S surf PMB measured at temperature 15°C

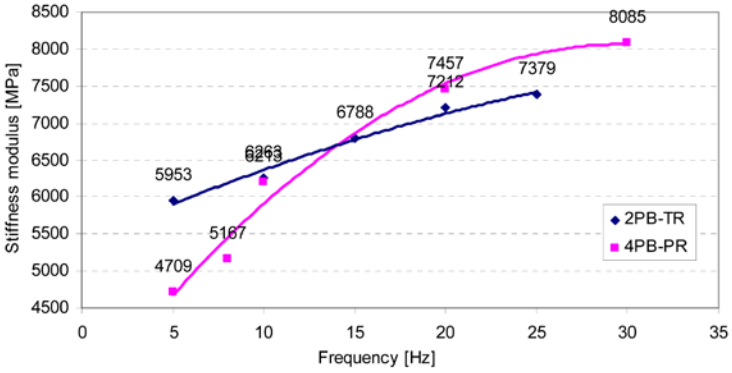


Figure 5 Results of stiffness moduli, AC16+ base bitumen measured at temperature 15°C

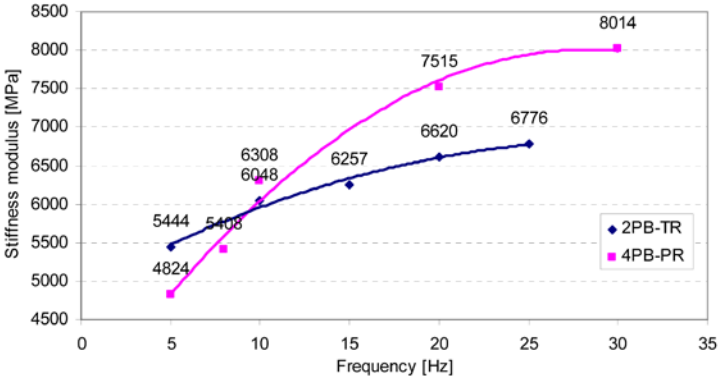


Figure 6 Results of stiffness moduli of AC22+, base bitumen measured at temperature 15°C

6 Conclusions

Stiffness moduli can be evaluated by different procedures and boundary conditions, based on standards EN 12697-26 and EN 13108-20 (2PB TR-15°C and 10 Hz; 4PB PR-20°C and 8 Hz), stiffness based modules for 2PB ranking 10 – 20 percent higher than the 4PB. Different AC's shows same pattern with respect to loading frequencies. It follows that the moduli based by stiffness parameters set in the European standard EN 13108-20 Type of 2PB and 4PB are not identical. This should lead to the question of underestimating thicknesses of individual pavement layers based on the 2PB TR design in the Czech Republic. Based on overall comparison the 2PB shows less dependency on frequency than the 4PB. Stiffness is more stable at higher frequencies around 30Hz.
Better results can be obtained using the temperature of 15° C for both methods. At these conditions similar results can be observed for different AC's and different bitumens at frequency range between 8 to 14 Hz.

Acknowledgements

The article was written with the support of the research projects of Czech Ministry of Transport CG712-043-910 "Management system of secondary materials for road structures in the Czech Republic", further 1F45B/066/120 "Introduction of European standards concerning the material specifications for improvement of the road serviceability, lifetime and traffic safety" and research project of Czech Ministry of Education MSM 0021630519 "Progressive reliable and durable constructions". For the Czech Technical university, this program was sponsored by VZ 01 CEZ MSM VZ 6840770001"Spolehlivost, optimalizace a trvanlivost stavebnich materialu a konstrukci" and GAČR 103/07/P537.
Project was also supported by the Association for the construction of roads Prague.

References

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[2] EN 12697-6 Bituminous mixtures – test methods for hot mix asphalt – Part 6: Determination of bulk density of bituminous specimens.

[3] EN 12697-26 Bituminous mixtures – test methods for hot mix asphalt – Part 26: Stiffness.

[4] EN 12697-33 Bituminous mixtures – test methods for hot mix asphalt – Part 33: Specimen prepared by roller compactor.

[5] EN 13108-20 Bituminous mixtures – Material specifications – Part 20: Type Testing