



RELIABILITY COMPARISON OF TWO-POINT AND FOUR-POINT BENDING TESTS FOR COARSE AGGREGATE MIXTURES

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Abstract

This paper investigates the reliability and comparative performance of two European standardized methods for assessing the stiffness and fatigue characteristics of asphalt mixtures with coarse aggregates up to 32 mm in grain size. European standards currently prescribe many various approaches to testing fatigue properties of asphalt mixtures, mainly two distinct methodologies: the two-point bending test and the four-point bending test. Despite the availability of both methods, certain laboratories predominantly prefer the two-point bending test. The study focuses on a comprehensive set of tests conducted on asphalt mixtures containing coarse aggregates with a maximum grain size of 32 mm, applying both the two-point and four-point bending tests. The primary objective is to assess the reliability of these methods, particularly in the context of larger aggregate sizes. A crucial consideration arises from the fact that the two-point bending test uses smaller specimens, potentially leading to an increased likelihood of test specimen failure in coarse aggregate asphalt mixtures. The experimental approach involves subjecting asphalt specimens to fatigue loading using both testing methods, systematically analysing the resulting data, and comparing the stiffness and fatigue performance outcomes. The findings contribute valuable insights into the appropriateness and reliability of the chosen testing methodologies, aiding practitioners and researchers in making informed decisions regarding the selection of fatigue testing protocols for asphalt mixtures with coarse aggregates.

Keywords: stiffness, fatigue characteristics, two-point bending, four-point bending, coarse aggregate

1 Introduction

The stiffness modulus and fatigue characteristics of asphalt mixtures are one of the fundamental parameters determined for asphalt mixtures. The resulting values of these parameters have a direct correlation with the pavement performance in situ. According to European standards, these parameters are determined by diverse methodologies, including the two-point bending test on trapezoidal specimens, two-point bending on prismatic shaped specimens, three-point bending on prismatic shaped specimens, four-point bending on prismatic shaped specimens, and an indirect stiffness assessment on cylindrically shaped specimens [1, 2].

This paper focuses primarily on the two-point bending test on trapezoidal specimens (2PB) and the four-point bending test on beam-shaped specimens (4PB). Results from these tests are subject to numerous influencing factors such as test geometry, aggregate gradation, bitumen grade, mixing and compaction temperatures, aging characteristics of the mixture or bitumen, production procedures, and equipment specifications [3, 4].

Hence, a question arises regarding the comparability of measured stiffness modulus and fatigue characteristic values from these respective testing methodologies. Several papers have explored fine-grained asphalt mixtures utilized in surface layers, revealing notable linear regression trends in stiffness modulus, but limited mostly to a maximum grain size of 11 mm [5]. Currently, there is increased pressure to develop new mixtures that primarily use less bitumen content, while efforts are also being made to reduce pressure on quarries to produce scarce fractions, such as the 8/11 mm fraction. Notably, no quarry has commenced operations in the Czech Republic since 1989. Currently, 225 quarries are operational, with an anticipated closure of mining activities in 145 quarries by 2032 [6].

Comparison between the 4PB and tensile tests revealed negligible levels of linear regression, potentially attributed to variances in loading equipment and parameters regarding temperature and frequency of loading specified by European standards [7]. Furthermore, the 2PB test has different testing parameters than these other tests, so a general discrepancy in the resulting stiffness modulus values by performing different tests can be expected. In the Czech Republic, the standard testing temperature for evaluating stiffness modulus using the 2PB test is maintained at 15°C. However, the testing temperature for the 4PB test is usually 20°C or 30°C. Both testing methodologies require sinusoidal loading curve during testing [8].

These two testing methods are also the basis for determining the fatigue of asphalt mixtures. The basic assumption of this test is that material fatigue occurs when its stiffness modulus decreases by 50%. When comparing the resulting fatigue values of common mixtures used in wearing courses evaluated using energy dissipation methods, which are based on the theory of energy balance, and traditional methods, a strong linear regression was found [9]. However, this may not always be the case because the results can be strongly influenced by coarse-grained mixtures, where consistent changes in stiffness moduli during the 2PB test are not expected, and failure during testing is also assumed in several cases.

Internationally, the difference in testing methodologies is all present. For example, in the US, the four-point bending test plays a critical role for mechanistic empirical design guide (MEPDG) which was the result of the strategic highway research program (SHRP). By comparing laboratory test results with field performance data, engineers can refine and improve the MEPDG models, leading to more reliable pavement designs [10]. The reliability and usability of 4PB test is still discussed in various international conferences, such as [8]. Many countries have done inter-laboratory comparison and research, for example RILEM [11] in Switzerland, which dives into the topic of various results depending on test type and mode of loading (stress and strain). The results of this study showed that the difference is mainly potent in testing of stiffness modulus, while the variability of tests did not influence resulting fatigue characteristics by considerable margin [3].

Some countries have already started to implement their own requirements for resulting modulus in asphalt mixtures and fatigue performance for most used methods. For example, Hungary has its requirements differentiated by test methods, temperature and loading frequency [7]. In France, the method which is used to determine stiffness or fatigue characteristics is not the determining factor, but the testing temperature and frequency are. Required results do not vary for different methods [12].

The coarsest mixture produced in the Czech Republic today is the AC 22 mixture for base layers, and the stiffness modulus of asphalt mixtures is mostly determined by the 2PB test. A disadvantage of this method for coarse-grained mixtures may be that the samples are allowed a maximum thickness of only 55 mm and the width at the top edge of the specimen of 25 mm. If the AC 32 mixture with a maximum grain size of 32 mm, which is gaining on popularity in Europe, were to be implemented more commonly in the future, this maximum sample thickness could be a problem for the consistency of stiffness test results. Tested specimens for the 4PB test exhibit larger dimensions across all axes compared to trapezoidal specimens for the 2PB test.

The goal of this work is to compare the reliability of mainly 2PB and 4PB tests for asphalt mixtures with a maximum grain size of 32 mm. As a result, this paper has recommendations onto which methods should be ideal for coarse aggregate asphalt mixtures, and whether the 2PB test is sufficient for these materials.

2 Mixture characteristics

As the pressure on coarser asphalt mixtures rises in the Czech Republic, the implementation of base course AC 32 with a maximum grain size of 32 mm is imminent. For this purpose, non-standardized mixture has been designed and mixed in the laboratory. The design of a new mixture originated by altering the already existing mixture AC 22 and moving the sieve size distribution to incorporate coarser aggregates.

As countries are implementing the asphalt mixture with aggregates up to 32 mm, they can be used as a reference in the design. The Swiss standard for the asphalt mixture AC T 32 is referenced in comparison [13]. To avoid any deviations by implementing polymer modifications, paving grade bitumen 50/70 was used to produce the mixture.

As a next step, several sets of Marshall specimens were manufactured to optimize the binder content and determine the volume weight. Final specifications of the mixture AC 32 are represented in a Table 1 and Table 2.

Table 1 Sieve size analysis for mixture AC 32

Sieve size [mm]	Passing the sieve for AC 32 [%]	Required passing the sieve for AC T 32 [%]
31.5	99.1	90 to 100
16	71.3	58 to 82
4	34.3	25 to 47
2	25.4	17 to 36
1	16.9	11 to 28
0.5	11.7	8 to 21
0.063	4.1	4 to 10

Table 2 Mixture specifications

Mixture	Bitumen content [%]	Void content [%]	VMA [%]	VFB [%]
AC 32	4.2	5.8	15.6	63

3 Experimental methods

3.1 Testing parameters

The stiffness (complex modulus) and fatigue characteristics of the mixture described in the section 2 were tested. The tests were 2PB test on trapezoidal specimens and 4PB test on prismatic shaped specimens. The conditions of those tests e.g., loading frequency and temperature, were chosen to comply with EN 13108 20 [14]. For stiffness, testing frequencies are 5, 10, 15, 20, 25 Hz and temperatures of 10, 15 and 20 °C. For fatigue test it is 10 Hz and 10 °C for 4PB whereas 25 Hz and 10 °C for 2PB. All the parameters are listed in the Table 3.

Table 3 Testing parameters

Testing method	Testing frequencies [Hz]	Specimen temperatures [°C]
2PB – stiffness	5, 10, 15, 20, 25	10, 15, 20
4PB – stiffness	5, 10, 15, 20, 25	10, 15, 20
2PB – fatigue	25	10
4PB – fatigue	10	10

3.2 Specimen dimensions

Dimensions of the tested specimen is one of the main differences in between various testing methods for stiffness or fatigue characteristics of asphalt mixtures. For 2PB, trapezoidal shaped specimens are being used, with the width at the base of 70 mm, at the top 25 mm, thickness of 55 mm and height of 250 mm.

For 4PB, prismatic shaped specimens are being cut. Used dimension for this test were limited by the testing machine capabilities. As by the standard, the thickness and width of a specimen should be 2.5D, which for the mixture AC 32 would be 80 mm. The maximal thickness and width possible to be tested in the available testing machine is 68 mm, which is the reason why it was chosen. The length of these specimen was set to 395 mm.

4 Results and discussion

4.1 Stiffness

Complex modulus of the asphalt mixture is recorded after 100 loading cycles to eliminate deviations occurring at the beginning of testing. The results were recorded on 11 and 18 specimens for 4PB and 2PB respectively. The average values of complex modulus at different testing temperatures are presented in Fig. 1.

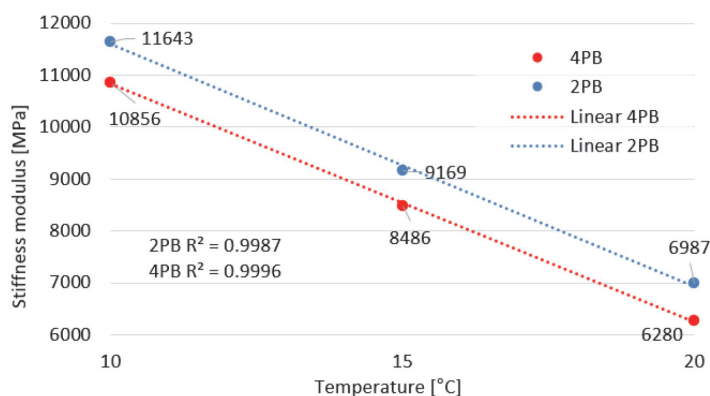


Figure 1 Stiffness modulus dependent on changing temperature

The most commonly emphasized value of stiffness modulus is determined at the testing temperature of 15 °C and frequency of 10 Hz. For this reason, the values of stiffness modulus is represented for temperature of 15 °C with changing frequencies in the next Fig. 2.

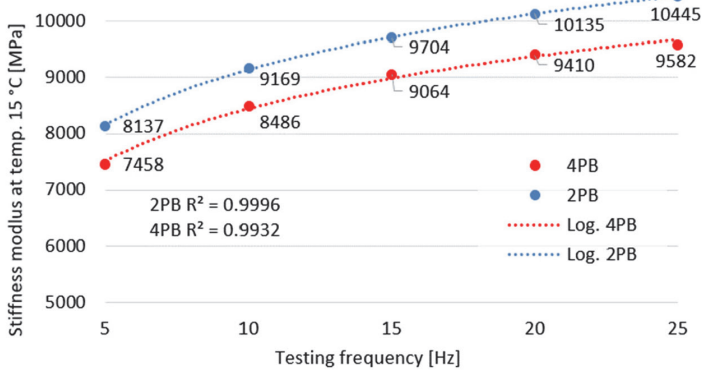


Figure 2 Stiffness modulus dependent on changing frequencies

4.2 Fatigue characteristics

The initial elastic strain of asphalt mixture is recorded after 100 loading cycles. Compared results of the tests are ϵ_6 , which represents the initial elastic strain required to reduce complex modulus by 50 % after 1 000 000 loading cycles, B, which serve as the slope of the fitted curve and the material susceptibility to stress, and lastly R^2 , which shows the reliability of results. All the results were made from 18 specimens after disregarding the specimen results deviating by an extreme margin. The results are represented in Table 4 and by Wöhler's diagram in Fig. 3.

Table 4 Results of fatigue tests

Testing method	ϵ_6 [$\cdot 10^{-6}$]	B	R^2
2PB	107.6	5.932	0.772
4PB	116.5	8.947	0.843

The required value of ϵ_6 for coarsest asphalt mixture in the Czech Republic is $100 \cdot 10^6$. This means, that the above specified mixture AC 32 meets the requirements set forward by the standard. For evaluation of fatigue characteristics, some specimen results were disregarded because of high deviation from the average. For 4PB, there were 2 specimens dismissed and for the 2PB test, the number of removed results was 7. This is speculated to be mainly because of the coarse aggregates in the mixture, as the fatigue crack in these disregarded trapezoidal specimens always occurred in the thinner part of specimen containing a coarse grain.

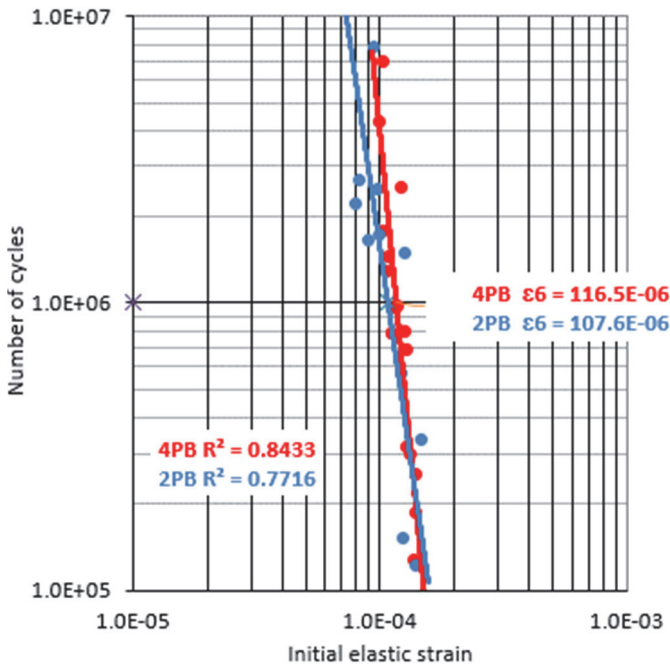


Figure 3 Wöhler's diagram

5 Conclusions

Stiffness of the mixture when testing using the 4PB test is on average 5 to 10 % lower than stiffness determined by 2PB test. This might be caused by different type of loading and specimen dimensions. However, resulting complex modulus for both tests performed at the most common testing temperatures has approximately linear progress dependent on the temperature change. The stiffness modulus change depending on loading frequencies is logarithmic for both performed test methods for temperatures ranging from 10 to 20 °C.

Fatigue characteristics of coarse aggregate mixture showed different results depending on the testing method. The 4PB test demonstrates better reliability with higher R^2 compared to 2PB test, higher elastic strain ϵ_6 , and higher B, which determines the susceptibility of material to stress. The reason for better results might also be in the testing frequencies which varied for both performed tests.

Overall, results of 4PB test are more reliable and thus representative of the mixture, mainly thanks to bigger dimensions of testing specimens. The results obtained from 2PB test are still reliable enough to be used in testing laboratories for coarse aggregate mixtures, as 2PB test requires much less labour and time to complete in comparison to 4PB test.

Acknowledgement

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