About the influence of several boundary conditions to results of the cyclic compression test

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ABSTRACT

The highly plastic and viscoplastic behavior of asphalt at high service temperatures possibly leads to irreversible deformations in form of rutting which significantly influence road safety. Therefore the deformation resistance is one of the most important usage properties of asphalt. To quantify the deformation resistance, besides wheel tracking, the uniaxial cyclic compression test as a special case of the triaxial cyclic compression test without lateral confinement is used in Germany. Thereby cylindrical asphalt specimens are exposed to a sinusoidal pulsed-shaped cyclic compression load with rest periods for 10.000 load cycles. The specimens may be fabricated by impact compactor, roller compactor or may be drilled out of asphalt pavement. As decisive parameter the strain rate at the inflection point of the pulse creep curve is to be determined. If the inflection point is not reached during the test the local tangent between the last 1.000 load cycles is considered the strain rate.

The deformation resistance is mostly influenced by asphalt composition (kind of binder, binder content, granulometry), volumetric parameters as the density and the compression ratio as well as the kind of compression. Within the project FE 07.0253/2011/ERB it was possible to quantify and qualify these influences for different pavement layers of 21 test sections. Thereby precious know-how with cyclic compression test was gained which will lead to a more detailed description of deformation properties of asphalt.

Keywords: Performance testing, Performance based standards, Permanent Deformation

1 INTRODUCTION

A very high percentage of the German as well as the European road network is built as asphalt pavement. Asphalt as a mixture of aggregates and bitumen as its binder has very complex performance-orientated properties. These properties mostly depend on the temperature-specific elastic, plastic, viscoplastic and viscoelastic behaviour of bitumen. As road pavements are highly exposed to different loading conditions at high service temperatures, permanent deformation as ruts may result. Heavy traffic loads have been increasing for the last decades and will certainly further increase in the next couple of years. Due to these rising heavy traffic loads more rutting will occur if the resistance of asphalts to permanent deformation at high service temperatures will not become an important issue to be enhanced. The resistance to permanent deformation therefore should be considered in the forefront of constructing to avoid early damage or deterioration.

To evaluate the deformation behaviour of asphalt at high service temperatures, dynamic laboratory tests have to be performed. In Germany the cyclic compression test without confinement stress is described in a technical test specification [1] and is used to evaluate the deformation behaviour. The cyclic compression test without confinement stress is a special case of the triaxial cyclic compression test with the confining stress set to zero which is regulated in the European asphalt specification EN 12697-25 [3]. Many years of experience with this laboratory test in Germany have shown that it is practical, reliable and a fast method to determine the deformation behaviour [4, 5]. For some special asphalt mixtures this laboratory test is part of the initial type testing. Nevertheless performance requirements for this type of test which are related to real rut depths have only occasionally been determined [4, 7, 8]. Furthermore a variety of possibilities to manufacture specimens and to prepare the asphalt samples are allowed in accordance to the technical test specification [1]. As these possibilities differ in compression type and composition characteristics as homogeneity, different results may be achieved for one and the same asphalt. An overview of the quality and quantity of these influences onto the deformation behaviour of asphalt at high service temperatures will be discussed here.

2 CYCLIC COMPRESSION TEST

The uniaxial cyclic compression test with no confinement stress is a practical, reliable and fast method to determine the deformation behaviour of asphalt. It has been developed and optimized in several research projects [6, 7, 8]. Therefore the German technical test specification [1] was updated several times to its effective revision from 2012. The short form “cyclic compression test” is used in this test specification and therefore within this paper. The test provides a possibility to address the deformation behaviour at high service temperatures with a dynamic load, in this case an axle-load-simulating dynamic load. In this test cylindrical specimens are subjected to a repeated sinusoidal haversine load with rest periods onto their base area at isothermal test conditions. As a consequence deformation occurs in the load direction. Some deformations are elastic or visco-elastic and decrease during the rest period, others stay irreversible. These irreversible deformations are recorded and evaluated for each loading cycle.

In accordance to the technical test specification [1] specimens may be prepared by impact compactor or out of drill cores. Cores furthermore may be drilled out of an asphalt pavement or roller compactor sample slabs produced in the laboratory. Specimens have to be grinded in an orthogonal-plan-parallel direction under wet conditions to a standard height of 60 mm. Core samples with a height less than 60 mm shall be fixed together with an adhesive to a total height of 60 mm after being grinded in orthogonal-plan-parallel direction to equal height each. As the influence of gluing is not known this practice is usually not applied. Figure 1 shows a scheme of the cyclic compression test.

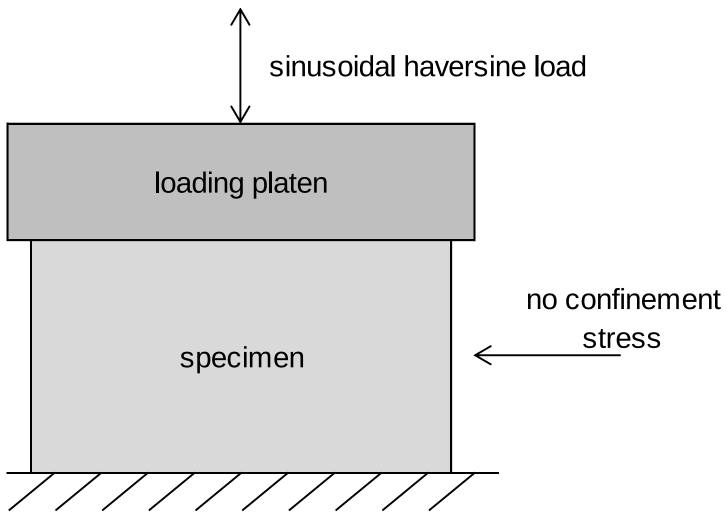

Figure 1: Schematic demonstration of the cyclic compression test

Test conditions as well as a visualisation of the stress distribution and the resulting deformation during the test are shown in figure 2. Test temperature is specified to 50 °C. The temperature may only be varied for specific questions as asphalt for tropic regions. The test is represented by a sequence of loading pulses each followed by a rest period. The loading pulse lasts for a duration of 0,2 seconds, the rest period lasts for 1,5 seconds. In total one loading cycle has a duration of 1,7 seconds. Normally 10.000 loading cycles are applied if the axial strain does not exceed the limit of 40 ‰. This amount of loading cycles is appropriate to characterise and compare different asphalt mixture designs exposed to the named test conditions regarding their resistance to permanent deformation at high service temperatures.

The stress arrangement is defined by a minimum stress σ_u and a maximum stress σ_o. The minimum stress has a constant value of 0,025 MPa and also has to be applied during the rest periods. The maximum stress during the loading cycles is set to 0,35 MPa. In the effective technical test specification [1] of 2012 the maximum stress is independent of the tested asphalt. In former editions of this test specifications the maximum stress was set to 0,20 MPa for asphalt concretes.

Specimen d/h: (100 ± 5) / (60 ± 1) mm

Loading platen diameter: ≥ 110 mm

Maximum stress σ_o: 0,35 MPa

Minimum stress σ_u: 0,025 MPa

Loading pulse duration: 0,2 sec

Rest period duration: 1,5 sec

Number of loading cycles: 10.000

Temperature: (50 ± 0,3) °C

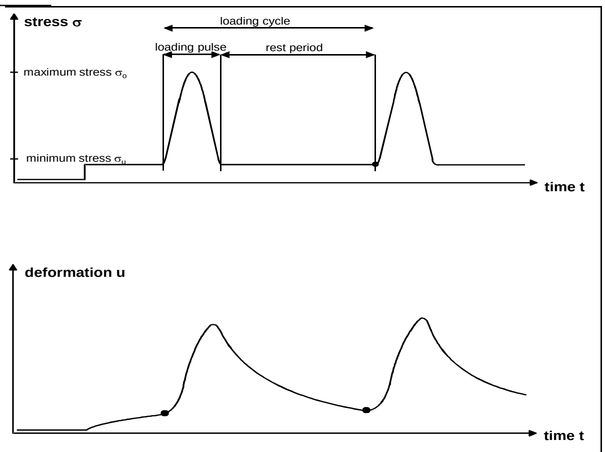

Figure 2: Test conditions in accordance to the technical test specification [1]

As shown at the bottom of figure 2 a minimum increase of permanent deformation of the specimen occurs after each loading cycle whilst applying the 10.000 loading cycles. The graphical examination of these accumulated permanent deformations over to the number of loading cycles is named impulse creep curve as shown in figure 3. This determined impulse creep curve is consulted to describe the deformation behaviour of asphalt. The most characteristic parameters are the number of loading cycles n, the strain ε in ‰ and the strain rate ε* in ‰·10^{-4}/n. The strain rate is specified as the slope of the local tangent in relation to the loading cycles n-100 and n+100. Therefore, in a mathematical sense, the strain rate correlates to the first derivative of the impulse creep curve. This means, the inflection point of the impulse creep curve correlates to the minimum of the strain rate. These parameters are either determined at the inflection point itself or if this stage has not been achieved, at the end of the test (n = 10.000). Figure 3 shows two examples, one with and one without an inflection point. An impulse creep curve with an inflection point is characterised by three phases. Phase 1 with strong deformations at the beginning of the test and progressive declining deformation rate. Phase 2 with a nearly constant deformation rate and an inflection point. In phase 3 the deformation rate is progressively increasing. Asphalts with a high resistance to permanent deformation e.g. rutting don't reach an inflection point during the test. Therefore phase 3 would not emerge.

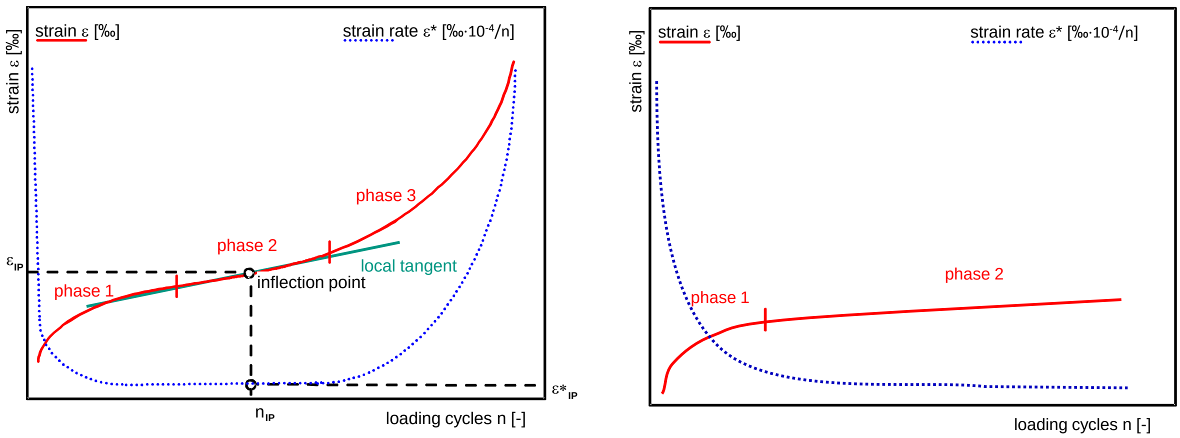

Figure 3: Typical impulse creep curves with (left) and without an inflection point (right)

3 DATABASE

The data of the following analyses is based on a research project funded by the German Federal Ministry of Transport, Building and Urban Development named "Representative Determination of Performance-relevant Asphalt Properties that Provide the Basis for New Conditions of Contract" [9] which was undertaken by the KIT and several partners. Within that project performance parameters during asphalt mixture design (stage EP) and production (stage MW) as well as after asphalt paving (stage BK) were systematically determined and evaluated for the asphalts for surface courses, binder courses and base layers found in 21 construction sites. The performance parameters determined were provided through tests of stiffness, low temperature cracking, deformation and fatigue as well as friction after polishing. For further analysis conventional asphalt properties as asphalt composition (bitumen type, bitumen content, granulometry), volumetric parameters as density and compression ratio as well as profound bitumen analyses were examined.

To evaluate the deformation behaviour the cyclic compression test was adopted. The asphalts for surface and binder courses are considered to be important for a high resistance against permanent deformation of the whole asphalt pavement and therefore were analysed in the research project. Furthermore all three stages of asphalt (EP, MW and BK) were probed. This also means that the specimens differ from each other concerning the mixing type and/or compression type: stages BK and MW are mixed in an asphalt mixing plant, stage EP is mixed in small scale at the laboratory. Stage BK is compacted in situ, stages MW and EP are roller compacted in the laboratory.

For possible future performance based contract conditions it is necessary to be able to forecast performance parameters of the asphalt pavement by known parameters evaluated in the laboratory at stage EP. Therefore a prognosis is tried to establish in the following chapters based on the results of the research project.

The total investigation covered 16 stone mastic asphalts (9x SMA 8 S, 5x SMA 11 S, 2x SMA 8 LA), four asphalt concretes (3x AC 11 D S, 1x AC 11 D N) and one mastic asphalt (MA 5 S) for the asphalts for surface courses and 18 asphalt concretes (13x AC 16 B S, 4x AC 22 B S, 1x AC 16 B N) and three stone mastic asphalts (3x SMA 16 B S) for the asphalts for binder courses. Table 1 gives an overview of the analysed asphalt mixtures and the used bitumen or resulting bitumen if asphalt granulates were added to the asphalt mixture. Those asphalts represent the commonly used asphalt mixture designs utilised for high traffic roads all over Germany.

Table 1: Overview of the analysed asphalts and their resulting bitumen

section no.	layer			
	asphalt surface course		**asphalt binder course**	
	asphalt	(res.) bitumen	asphalt	(res.) bitumen
1	SMA 11 S	25/55-55 A	AC 16 B S	25/55-55 A
2	AC 11 D N	50/70	AC 16 B N	50/70
3	SMA 8 S	PmB NV 45	AC 16 B S	25/55-55 A
4	SMA 8 S	PmB NV 45	AC 16 B S	25/55-55 A
5	SMA 11 S	25/55-55 A	AC 16 B S	25/55-55 A
6	SMA 8 LA	40/100-65 A	SMA 16 B S	10/40-65 A
7	AC 11 D S	25/55-55 A	SMA 16 B S	10/40-65 A
8	SMA 8 S	25/55-55 A	AC 16 B S	25/55-55 A
9	SMA 8 S	25/55-55 A	AC 16 B S	25/55-55 A
10	AC 11 D S	25/55-55 A	AC 16 B S	25/55-55 A
11	SMA 8 S	25/55-55 A	AC 22 B S	25/55-55 A
12	SMA 8 S	25/55-55 A	AC 16 B S	25/55-55 A
13	SMA 8 S	25/55-55 A	AC 16 B S	25/55-55 A
14	AC 11 D S	25/55-55 A	AC 16 B S	25/55-55 A
15	MA 5 S	20/30	AC 16 B S	10/40-65 A
16	SMA 11 S	25/55-55 A	AC 22 B S	25/55-55 A
17	SMA 11 S	25/55-55 A	AC 16 B S	25/55-55 A
18	SMA 11 S	25/55-55 A	AC 22 B S	25/55-55 A
19	SMA 8 S	25/55-55 A	AC 22 B S	10/40-65 A
20	SMA 8 S	25/55-55 A	AC 16 B S	10/40-65 A
21	SMA 8 LA	40/100-65 A	SMA 16 B S	10/40-65 A

4 DEFORMATION VALUES OF ASPHALT AT DIFFERENT STAGES

The in situ compacted specimens at stage BK made it necessary to reduce the maximum stress during the cyclic compression test to 0,2 MPa as the strain rates and the strains itself were extraordinary high with the usual test conditions. Furthermore the specimen height of asphalts for surface courses at stage BK were showing heights of 40 mm or less and were examined at that condition. For comparability reasons the specimens at the stages MW and EP were also manufactured to that height and were probed at a maximum stress of 0,2 MPa. All other test conditions were applied as explained in chapter 2. Analyses of the influence of the specimen height reduced to 40 mm instead of 60 mm showed that for roller compacted sample slabs the strain rates are statistically the same irrespective of the specimen height.

4.1 ASPHALT FOR SURFACE COURSES

Figure 4 illustrates the results of the cyclic compression test on asphalt for surface courses at all three stages. This illustration differs between asphalt mixtures and bitumen as well as the eventual reaching of an inflection point (tiled hatching). Some tests even had to be stopped after a deformation of 40 ‰ was exceeded (striped hatching). Instead of the cyclic compression test the uniaxial cyclic compression test with some confinement [2] was applied for mastic asphalts (section 15). The result of that test method is the dynamic penetration in mm.

Figure 5 demonstrates the grouped average results of the cyclic compression tests as well as the minimum and the maximum in each group of asphalt for surface courses at all three stages.

For clarity reasons figures 4 and 5 are cut at a strain rate of 100 ‰·10^{-4}/n although some asphalt mixtures exceed this value.

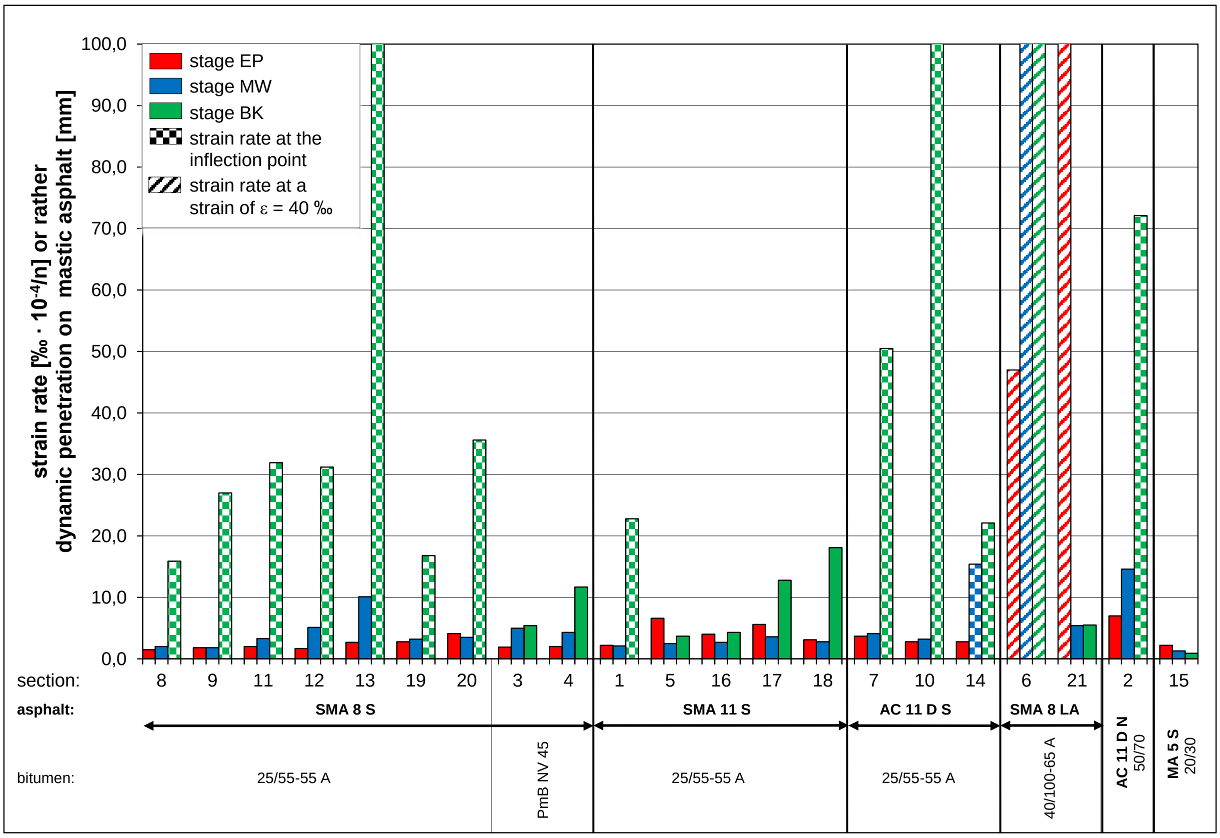

Figure 4: Results of the cyclic compression test on asphalt for surface courses

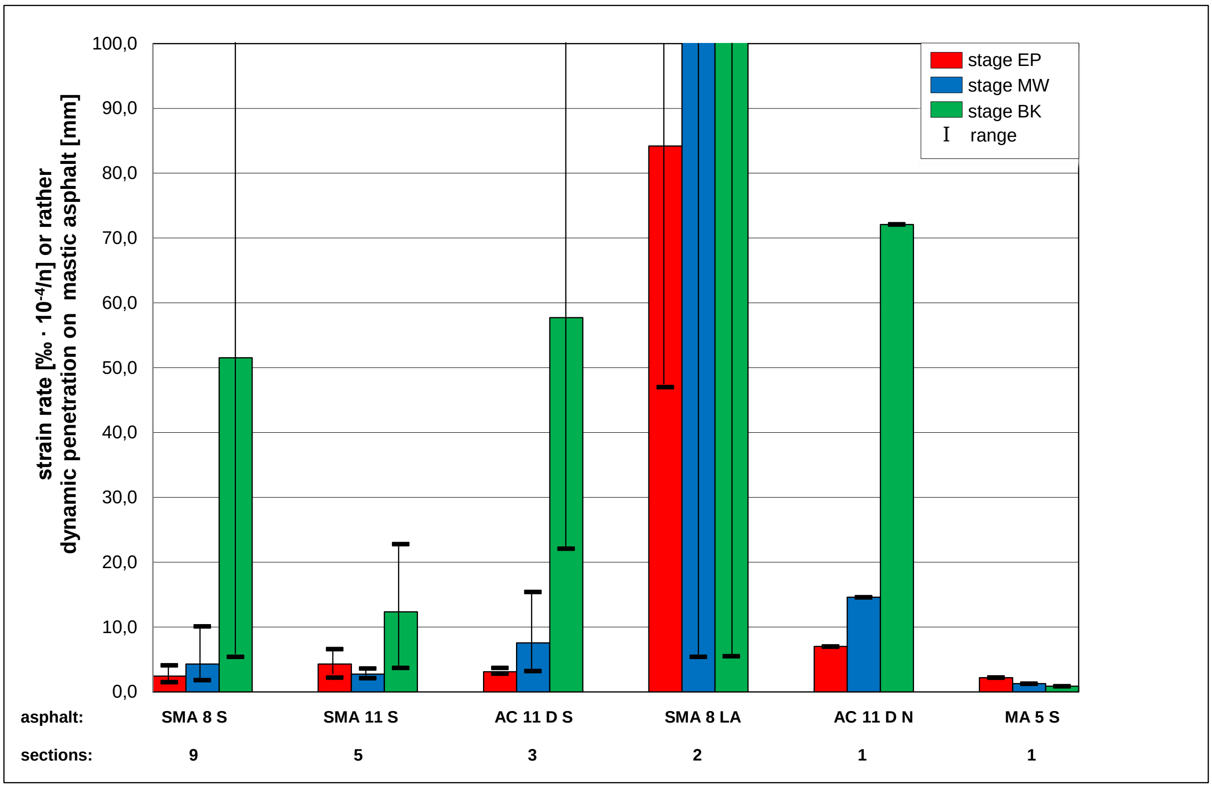

Figure 5: Grouped results of the cyclic compression test on asphalt for surface courses

The comparison of the averages of the different stages (figure 5) points up the decisive influence of the specimen production onto the results of the cyclic compression test. It is clearly visible that specimens obtained from the asphalt pavement (stage BK) tend to show higher strain rates than specimens manufactured in the laboratory by roller compactor (stages MW and EP). In twelve of 20 cases the drill cores show inflection points during the course of the impulse creep curve, at stage MW only in one case and at stage EP no inflection point occurs (figure 4). The differences in the specimen production or rather the compression type accompanied by differing levels of bulk density as well as aggregate orientation are expected to be the most relevant influences to explain these results. With the statistical evaluations that have been undertaken within the research project it has to be stated that stage BK statistically differs significantly from stages EP and MW in eight of nine cases for the SMA 8 S, in three of five cases for the SMA 11 S and in three of three cases for the AC 11 D S. In seven of nine cases for the SMA 8 S, in two of five cases for the SMA 11 S and in two of three cases for the AC 11 D S no statistically significant differences between the stages MW and EP were found.

Stone mastic asphalts SMA 11 S tend to show lower strain rates (figure 4) and e.g. a higher resistance to deformation at stage BK when using bitumen PmB NV 45 instead of 25/55-55 A. This may support the assumption that bitumen with lower viscosity lead to a higher resistance to permanent deformation of the asphalt pavement.

Regarding the two SMA 8 LA within the database it has to be considered that the cyclic compression test is not a suitable method to determine the deformation behaviour of asphalt mixtures with a high void content. In four of six cases the test had to be stopped after a deformation of 40 ‰ was exceeded.

Therefore it may be summarised that in most cases (twelve of seventeen) the resistance to deformation at stages MW and EP is statistically the same. The strain rate at stage BK is in average about ten times as high as at stages MW or EP. Nevertheless no distinct indicators in conventional asphalt or bitumen properties were found that allow a precise prognosis to evaluate the resistance to deformation at stage BK based on the properties determined at stage MW or EP.

4.2 ASPHALT FOR BINDER COURSES

Figure 6 illustrates the results of the cyclic compression test on asphalt for binder courses at all three stages. This illustration differs between asphalt mixtures and bitumen as well as the eventual reaching of an inflection point (tiled hatching).

Figure 7 demonstrates the grouped average results of the cyclic compression tests as well as the minimum and the maximum in each group of asphalt for binder courses at all three stages.

For clarity reasons figures 6 and 7 are cut at a strain rate of 100 ‰·10^{-4}/n although one asphalt mixture exceeds this value.

By comparing the averages of the different stages (figure 7) a slight tendency is determined that the strain rates at stage BK are higher than at stages MW and EP and therefore an influence of the specimen production or rather the compression type onto the results of the cyclic compression test is observed. At stage BK inflection points occur in twelve of 21 cases. Increasingly, inflection points also occur at stages MW and EP, which may neither be definitely explained through abnormalities in composition nor through the bulk densities of the specimens. An inflection point occurs in six cases each at stages MW and EP (figure 6). For two test sections inflection points occur at all stages and for six test sections no inflection point occurs at any stage.

For the most common asphalts for binder courses in Germany (AC 16 B S, AC 22 B S and SMA 16 B S) it may be summarised that quite large spreads of the strain rates occur at all stages (figure 7). With the statistical evaluations that have been undertaken within the research project it has to be stated that the statistical significance tendencies dramatically differ between most test sections. For the AC 16 B S in seven of thirteen cases the highest strain rate occurs at stage BK, in four cases at stage EP and in two cases at stage MW. For the AC 22 B S in three of four cases the highest strain rate occurs at stage BK and in one case at stage MW. In two of three cases the highest strain rate occurs at stage BK for the SMA 16 B S, in one case the strain rate is about the same at all three stages. The strain rate at stage BK in average is about twice as high as at stages MW or EP for the AC 16 B S. For the AC 22 B S the strain rate at stage BK is in average about twice as high as at stage MW, but about ten times as high as at stage EP. Regarding the three SMA 16 B S the strain rate at stage BK in average is about five times as high as at states MW or EP, the strain rates at the stages MW and EP are statistically the same. Consequently no distinct indicators in conventional asphalt or bitumen properties were found that allow a precise prognosis to evaluate the resistance to permanent deformation at stage BK based on the properties determined at stage MW or EP.

Asphalt concretes AC 16 B S and AC 22 B S in average tend to show lower strain rates (figure 4) and e.g. a higher resistance to permanent deformation at stage BK when using bitumen 10/40-65 A instead of 25/55-55 A. This may support the assumption that bitumen with lower viscosity lead to a higher resistance to permanent deformation of the asphalt pavement.

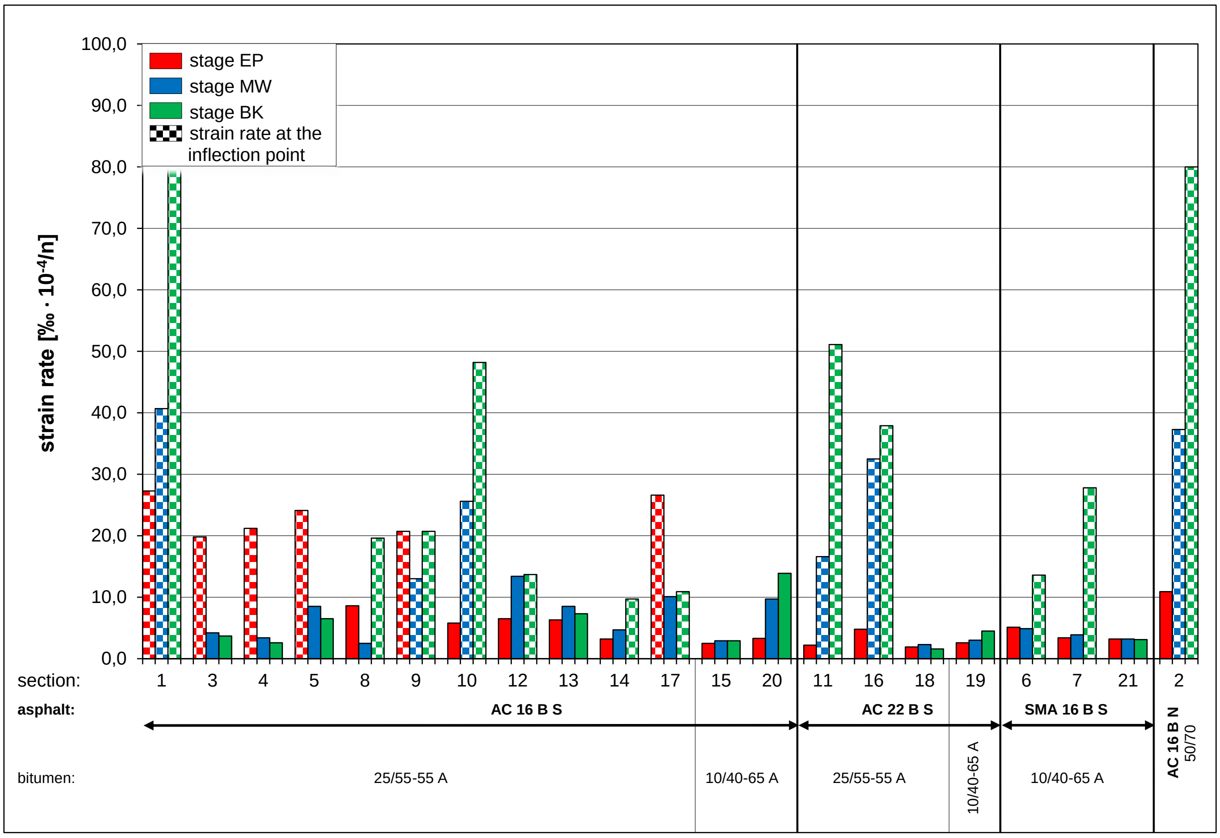

Figure 6: Results of the cyclic compression test on asphalt for binder courses

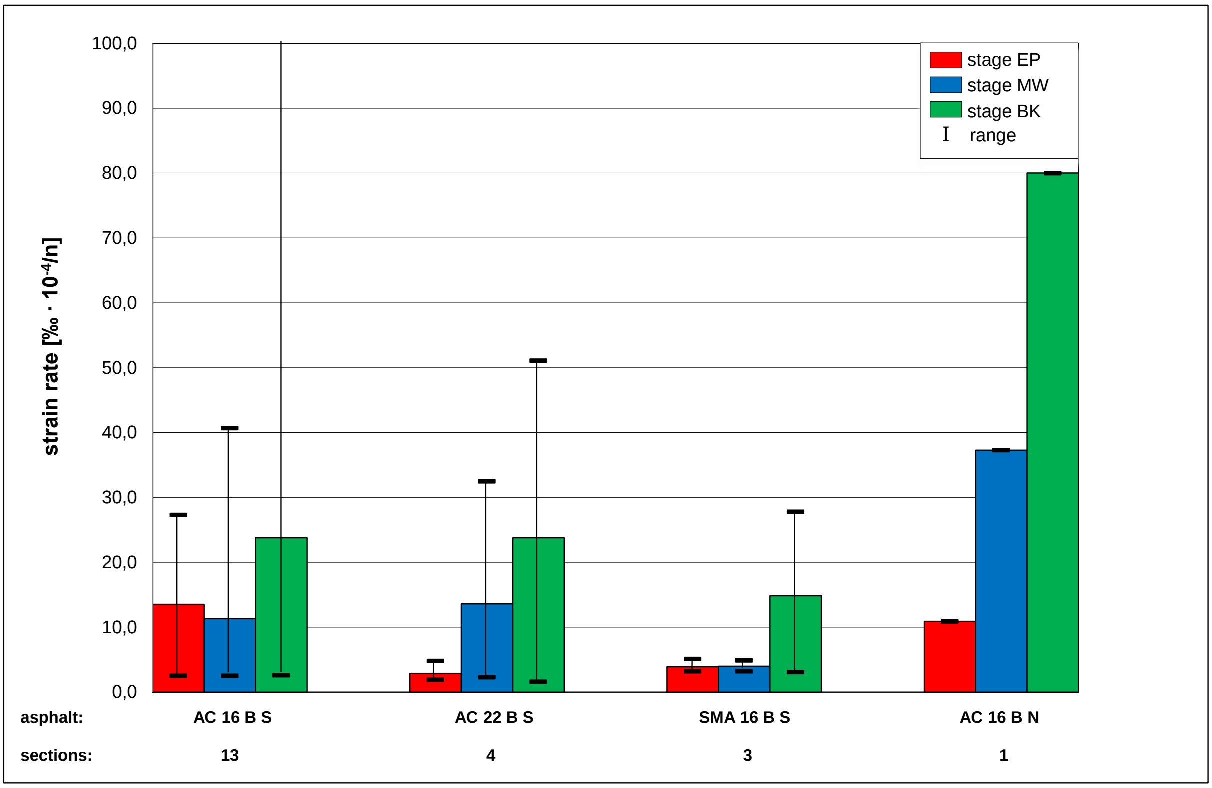

Figure 7: Grouped results of the cyclic compression test on asphalt for binder courses

5 SUMMARY

For the most common rolled asphalts utilised for high traffic roads all over Germany it may be summarised that the resistance to permanent deformation at the stages EP and MW significantly distinguishes from that at stage BK. The average strain rate of different asphalt mixture types at stage BK is up to ten times as high as at stages EP or MW.

For the asphalts for surface courses overall at stage BK stone mastic asphalts SMA 11 S show the highest resistance to permanent deformation. Stone mastic asphalts SMA 8 S with low-viscos bitumen PmB NV 45 behave analogous. However in utilisation of 25/55-55 A the resistance to permanent deformation is clearly lower. Generally asphalt concretes AC 11 D S and AC 11 D N probed at stage BK are a bit more susceptible to permanent deformation compared to the stone mastic asphalts SMA 11 S. However at stages EP and MW partially a similar high resistance to permanent deformation was determined.

For the asphalts for binder courses overall at stage BK stone mastic asphalts SMA 16 B S show the highest resistance to permanent deformation. Binders AC 16 B S and AC 22 B S produced with bitumen 10/40-65 A in average show lower strain rates in comparison to the ones with 22/55-55 A and no inflection points occur at any stage. In average the binders AC 16 B S and AC 22 B S compared to each other show similar strain rates at stages BK and MW. At stage EP the resistance to permanent deformation of AC 22 B S is clearly higher.

Distinct statements concerning the influences of asphalt composition or rather variances in between asphalt composition at different stages as well as the bitumen properties onto the results of the cyclic compression test could not be derived. Increased bitumen contents may be a potential explanation for tending to higher strain rates and bitumen with lower viscosity are a potential explanation for tending to lower strain rates. Apart from that the strain rates at stages EP and MW in average correspond to each other and in most cases are located clearly below the ones at stage BK.

Still the tests performed within the research project proved that the cyclic compression test is a practical, reliable and fast method to determine the deformation behaviour and to differ between asphalt mixtures designs to find the ideal one for a special application for example by utilising low-viscos bitumen. This means the cyclic compression test may be used very well at stage EP to determine future rutting although different values are measured when testing drill cores from the asphalt pavement.

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