Determination of relevant input parameters for the analytical pavement design of asphalt pavements – laboratory tests

S. Lipke & P. Kukies
Federal Highway Research Institute, Germany
Lipke@bast.de, Kukies@bast.de
F. Wellner
Dresden University of Technology, Germany
Frohmut.Wellner@tu-dresden.de

ABSTRACT

Aim of this research project is substantially improve the consideration of asphalt properties within the analytical pavement design. Basis of this project was the systematic variation of the components/parameters – aggregate, bitumen (origin, classification), binder content and void content – of asphalt base courses (ATS-mixes). Fatigue tests and tests to determine the E-Modulus (Indirect-Tensile-Test (ITT), Four-Point-Bending-Beam-Test (4PBT)) have been conducted on these ATS-mixes. The effects (components/parameters) on the fatigue behaviour and the E-Modulus have been identified.

Summarizing it initially can be noted that for ATS-mixes with different aggregates and same bitumen differences of up to 20 % in the sizes of the E-Modulus determined by ITTs are observed. Furthermore the results with the ITTs show an increase of the E-Modulus with rising binder content of the tested ATS-mixes. While with their rising void content a decrease of the E-Modulus was detected.

If the fatigue functions of all tested ATS-mixes are compared, the ATS-mixes with polymer-modified bitumen (PmB) show a significant higher resistance against fatigue than the ATS-mixes with normal bitumen. Further the fatigue tests prove that the bitumen origin may have a remarkable influence on the fatigue resistance of asphalt mixes. In addition it became evident that the fatigue resistance rises with rising degree of compaction and the binder content substantially affects the fatigue resistance.

Comparing the E-Modulus of the same ATS-mix once determined with ITTs and once with 4PBTs the E-Modulus got from the 4PBTs had been higher than those from the ITTs (kind of test, test conditions). The fatigue functions of the ATS-mixes determined with the two different tests are shifted parallel and ranked identically. A nearly linear correlation between the amounts of fatigue load cycles of the same ATS-mixes determined with 4PBTs respectively ITTs (ratio 5:1) could be noted.

Finally pavement design calculations to estimate the effects of the determined differences of the asphalt-mixes have been conducted. Summarizing it was detected, that the binder properties have a significant influence on the material behaviour of the asphalt-mixes. In combination with suitable performance orientated laboratory tests the results of this research project allow to detect the mechanical behaviour of asphalt-mixes and thus use it for analytical design of pavements.

Furthermore the investigations pointed out that using PmB improves the material behaviour of asphalts and thus the life-cycle of pavements extends with application of PmB in ATS-mixes. This also guarantees a careful use of resources and leads to a significant contribution to reducing CO_2-emissions (energy-efficiency).

1 INTRODUCTION

Analytical pavement design in Germany is currently restricted on the usage of standard pavements in accordance with the RStO [1], meaning the layer thicknesses of pavements are determined on the basis of results obtained empirically. A determination of stress in pavements and derived computational proof for pavement design has not yet been performed in Germany. It is for this reason that an analytical procedure for the design of flexible pavements has been developed, which is described in detail in the RDO-Asphalt [2].

A prerequisite for the design is the realistic description of the tension and deformation behaviour of the road pavement and the material-technical characterisation of the building materials. Due to traffic and climate, the determinable stress condition of pavements forms the basis of the analytical pavement design. It is hereby necessary to determine the stress condition of the pavement using a calculation method that takes the behaviour of the road materials used as well as the properties of the subsoil/subgrade into consideration. Thereafter it is possible to estimate the service life using various damage criteria. In particular, the asphalt package is to be examined for risk of fatigue cracking and the formation of ruts.

Based on the analytical procedure for the design of flexible pavements, the design program PaDesTo was developed in accordance with RDO-Asphalt. This represents a tool which can be used both for the design and substance-related evaluation of asphalt pavements, with the specification of necessary input parameters.

2 RESEARCH OBJECTIVES

Within the framework of the design of flexible pavement in accordance with RDO-Asphalt, concerning the fatigue the stiffness-temperature-functions and fatigue behaviour of the asphalt base course (ATS) are used for the material-technical description of the asphalt mixes. For simplification purposes, the Francken/Verstraeten method [4] can be used for the computational estimation of the stiffness-temperature-functions, for asphalt mixes. However, this can only be done on the condition that the asphalt is put together by the principle of asphalt concrete and that normal bitumen, i.e. not polymer modified bitumen (PmB) is used. This not only allows for the determination of the E-modulus dependent on temperature and frequency, but also the consideration of the composition of the asphalt mix. As a matter of principle however, laboratory tests are required for a significantly more accurate determination of the E-modulus.

Depending on the composition of the asphalt mixes, and in particular the bitumen used, different asphalt mixes show a very different stiffness and fatigue behaviour [5]. Therefore, the E-Modulus and fatigue functions for the selected asphalt mixes, determined by laboratory tests, cannot be applied to other asphalt mixes. Thus for example, the use of polymer-modified bitumen PmB instead of normal bitumen can markedly improve the fatigue behaviour of asphalt mixes.

Systematic studies of the asphalt mixes currently used in German road construction, regarding the impact of the mixture parameters on the stiffness and fatigue behaviour of the ATS, have not been conducted yet. Therefore, no generally applicable forecast tools for design relevant asphalt properties for asphalts used in Germany, based only on the properties of the mixture components or mixture recipes, are available. However, a detailed consideration of the actual asphalt properties within the framework of the analytical design is one of the most significant components for a suitable and economic adaptation of the layer thicknesses to the respective local conditions. It was therefore the aim of the study to significantly improve the thus far limited possibility of taking the asphalt properties for the analytical design of pavements for practical applications into consideration.

3 LABORATORY TESTS

The usage behaviour of asphalt pavement is largely determined by the resistance to plastic deformation and resistance against fatigue (cracking). The deformation characteristics and strength properties of asphalt can be characterised by the following mechanical properties:

- Elastic deformation behaviour (stiffness)
- Plastic deformation behaviour
- Fatigue behaviour

These properties are essential for the design of asphalt pavements. Currently, asphalt composition is mainly optimised with respect to the resistance against plastic deformation. Resistance to cracking is often taken into account insufficiently. Both fatigue cracks, due to repeated traffic exposure (e.g. longitudinal cracks next to the wheel track), and rutting, are the most commonly observed damages to asphalt pavements [7].

A variety of tests were developed to detect cracking formation (e.g. Three-Point-Bending-Beam-Test, Four-Point-Bending-Beam-Test, Indirect-Tensile-Test and Direct-Tensile-Test). The need arose to select a relatively simple, cost-effective and quick test method from the available test methods, for the recognition of crack formation, with which the actual stress conditions for road pavements can be simulated as accurately as possible. The Indirect-Tensile-Test is such a test method.

Based on the results of the Indirect-Tensile-Test, the required input parameters for an analytical pavement design in respect to crack formation (stiffness-temperature-function and fatigue function) can be determined. The test results are significantly influenced by the selected test conditions and highly dependent on the mixture composition.

4 TESTED MATERIALS

Within the framework of the research project, ten ATS mixes were tested. Three types of aggregates and eight types of bitumen were applied, whereby amongst others, bitumen of the same specification but of different origins was used. Furthermore, the void content and binder content were varied for the selected mixtures. The tested asphalt mixes are listed in Table 1. The composition of the mixtures was based on the results of initial type tests.

Table 1 Tested ATS- mix names

name	aggregate	bitumen	origin	void content [Vol.-%]	binder content [mass %]
G1B1	Grauwacke	50/70	A	6,5	3,9
G1B2	Grauwacke	70/100	A	6,5	3,9
G1B3	Grauwacke	30/45	A	6,5	3,9
G1B4	Grauwacke	50/70	B	6,5	3,9
G1B5	Grauwacke	PmB 45 A	B	6,5	3,9
G1B6	Grauwacke	PmB 45 A	D	6,5	3,9
G1B7	Grauwacke	PmB 45 A	A	6,5	3,9
G1B8	Grauwacke	50/70	C	6,5	3,9
G2B1	Diabas	50/70	A	6,5	3,7
G3B1	Granodiorit	50/70	A	6,5	4,0
G1B11	Grauwacke	50/70	A	6,4	4,4
G1B12	Grauwacke	50/70	A	6,4	4,9
G2B11	Diabas	50/70	A	6,5	4,2
G2B12	Diabas	50/70	A	6,4	4,7
G3B11	Granodiorit	50/70	A	6,4	4,5
G3B12	Granodiorit	50/70	A	6,5	5,0
G1B13	Grauwacke	50/70	A	8,5	3,9
G1B14	Grauwacke	50/70	A	5,7	3,9
G1B0	Grauwacke	50/70	A	6,5	4,2

Figure 1 shows the grading curve of the aggregates used in the ATS mixes. In the laboratory, the plates were produced by roller compaction, from which the cylindrical specimens were drilled for the Indirect-Tensile-Test.

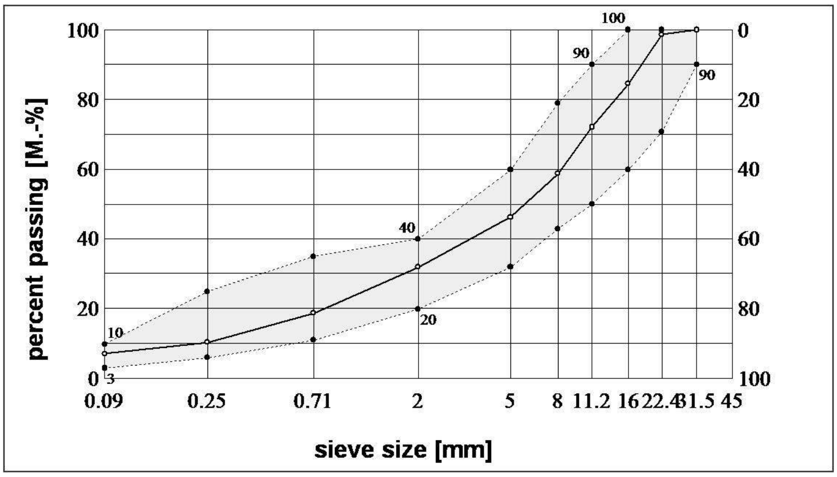

Figure 1 – Grading curve of aggregates

5 LABORATORY TEST RESULTS – E-MODULUS

5.1 General

In order to determine the E-modulus, Indirect-Tensile-Tests were conducted for all asphalt mixes at a frequency of 10 Hz and at four different test temperatures (-10, 0, 10 and 20 °C), in accordance with the AL Sp-Asphalt 09 [7]. Force-controlled harmonic sinusoidal fatigue stress, without load break at a lower stress of 0,035 N/mm², was applied to the specimen.

Based on the results of Indirect-Tensile-Test, a stiffness-temperature-function could be established for each ATS mix. These functions constitute one of the most important input parameters for the analytical pavement design of asphalt pavements. Furthermore, tests on the asphalt mixes and binders were conducted in order to determine input parameters for the determination of the stiffness-temperature-function according to the Francken/Verstraeten method. In this context, the softening point ring and ball, the penetration values and the asphalt maximum density for the individual ATS mixes were determined. Subsequently, the calculated stiffness-temperature-functions were compared to the E-Modulus determined by testing, in order to assess the accuracy of the Francken/Verstraeten method.

When comparing the E-Modulus determined by testing with the E-Modulus determined by calculation, it was observed that the detection of the stiffness-temperature-function, according to the Francken/Verstraeten method, results in significantly higher values for asphalt mixes tested at lower temperatures (< 0 °C) compared to the values determined by laboratory testing (Figure 2). At a test temperature of 20 °C this ratio is reversed.

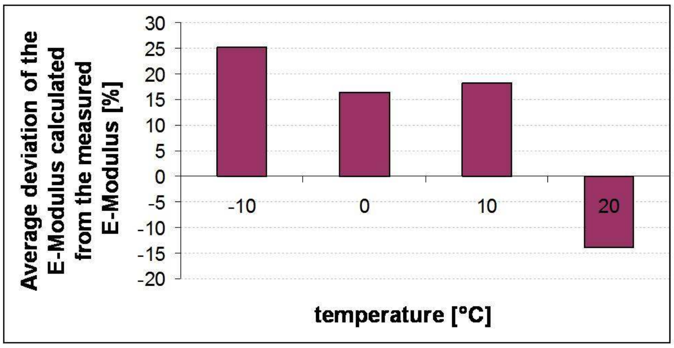

Figure 2 – Average deviation of the E-Modulus calculated according to the Francken/Verstraeten method, from the measured E-Modulus depending on the temperature.

5.2 Influence of binder hardness and origin

Studies by Gauthier et al. [5] have shown that the binder properties have a significant influence on the stiffness of asphalt mixes (here: asphalt concrete). These observations were confirmed by the tests conducted within the framework of the project. Figure 3 illustrates that the use of harder binders tends to result in a higher E-modulus for asphalt mixes.

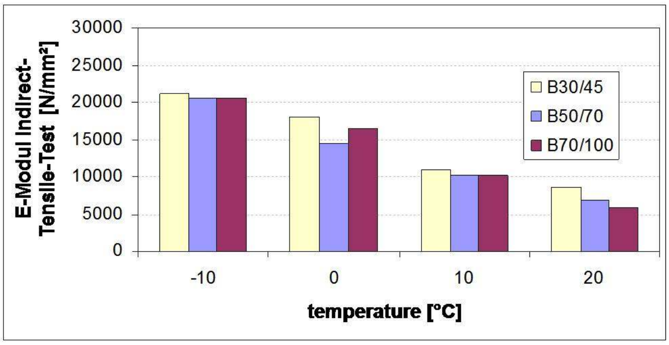

Figure 3 – E-Moduli determined by Indirect-Tensile-Tests for ATS mixes – aggregate 1 and normal bitumen of different binder hardness.

Furthermore, it was detected that the ATS-mix containing bitumen of origin B, has the highest E-Modulus (approx. 10 to 20% higher) out of the ATS mixes with normal bitumen 50/70 (Figure 4).

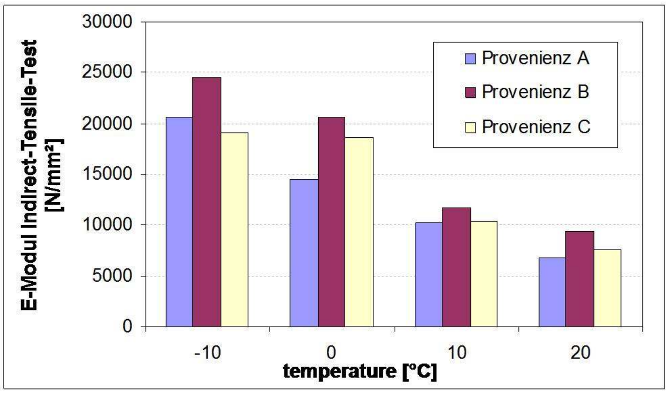

Figure 4 – E-Moduli determined by Indirect-Tensile-Tests for ATS mixes – aggregate 1 and normal bitumen of different origin.

This means that bitumen with the same specification (here: 50/70) can most certainly feature different properties, which significantly affect the deformation behaviour of asphalt mixes. Furthermore, the test results make it clear that the methods and tests for the specification of bitumen (softening point ring and ball, penetration) currently applied in Germany, do not appear to make an extensive classification of bitumen, or the determination of bitumen properties, which are relevant for the behaviour of asphalt mixes (here: stiffness), possible.

5.3 Influence of the aggregate

Figure 5 shows the influence of the different aggregates on the E-Moduli for the tested ATS mixes. It can be seen that the aggregate used has a noticeable influence on the material behaviour of the asphalt mixes. So far however, it could not be determined whether these differences are due to the deformability of the aggregate, the surface structure of the grains or to the binder properties. In this context, a range of variation of the E-Moduli for the tested ATS mixes of 20 % can be detected, due to the use of different aggregates.

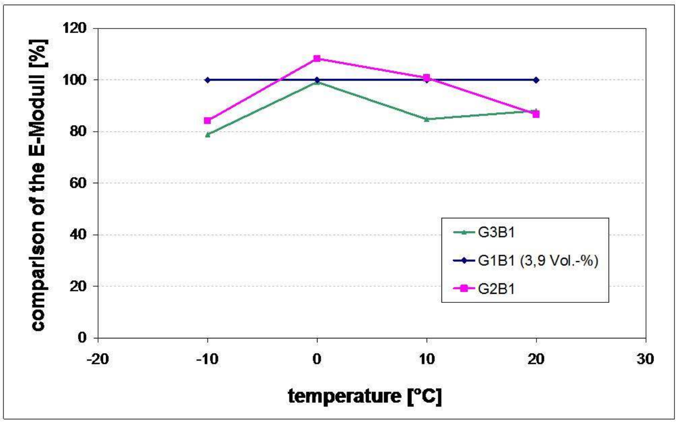

Figure 5 – Comparison of the ATS-mix E-Moduli at a frequency of 10 Hz (different aggregates and normal bitumen 50/70) (the E-Moduli of the ATS-mix G1B1 were equated at 100 %).

5.4 Influence of binder content

The results of the Indirect-Tensile-Tests show that for the tested ATS-mixes, in particular at a test temperature of 0 °C, an increase in the E-Moduli occurs with increasing binder content (Figure 6). However, it is to be expected that a maximum E-Modulus will be achieved at a certain level of binder content, in dependency of temperature.

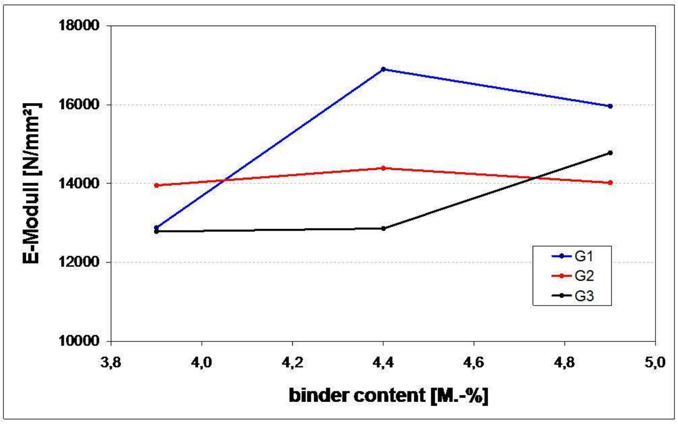

Figure 6 – E-Modulus dependent on binder content at a test temperature of 0 ° C, Indirect-Tensile-Test result

Figure 6 shows that, a maximum E-Modulus was achieved at a test temperature of 0 °C for the ATS-mixes with an aggregate mix of G1 and G2, at a binder content of 4,4 mass %. In the case of further rising binder content, the E-Moduli of these ATS-mixes decrease again. This correlation is temperature dependent. This means that the maximum E-Moduli can occur at different temperatures for different binder content. The maximum E-Modulus occurs at a binder content of 4,9 MASS % for all test temperatures for the ATS-mix with aggregate G3 (Granodiroit-Mikrogabbro). The higher binder content required to reach the maximum E-Modulus for the ATS-mix with aggregate G3, compared to the ATS-mixes with aggregate G1 and G2, could possibly be due to the lower maximum density of aggregate G3.

Based on these results, an approach for the development of a performance based initial type test for asphalt mixes in respect of deformation behaviour could be derived. In addition, it should be mentioned that not only should the E-Moduli of ATS-mixes be considered, but also the fatigue behaviour (fatigue functions). In turn, the binder content influences the position and increase of the fatigue functions. Therefore, within the framework of a performance based initial type test, mix optimisation concerning the E-Modulus and fatigue behaviour needs to occur. The higher E-Moduli at higher binder contents result in lower tensile strains in the asphalt package. Higher binder content usually results in an improvement of the resistance against fatigue. For this reason, such an approach to a performance-based initial type test can only be used in correlation with design calculations.

5.5 Influence of void content

It is known that the void content and degree of compaction of the asphalt layers substantially influence the E-Modulus and fatigue behaviour. It is for this reason that the effect of the void content, due to the change in the degree of compaction on the E-Modulus, was tested on the ATS-mix G1B1. In one context, the void content was reduced by 1,0 Vol.-% (G1B14), in a second context it was increased by 2,0 Vol.-% (G1B13).

As a result of the tests, it became clear that a reduction of the void content from 6,4 to 5,4 Vol.-% results in a significant increase of the E-modulus (stiffness-temperature-function shifted parallel). An increase of the void content from 6,4 to 8,4 Vol.-% resulted in no significant change of the E-Modulus for the tested ATS-mix (Figure 7).

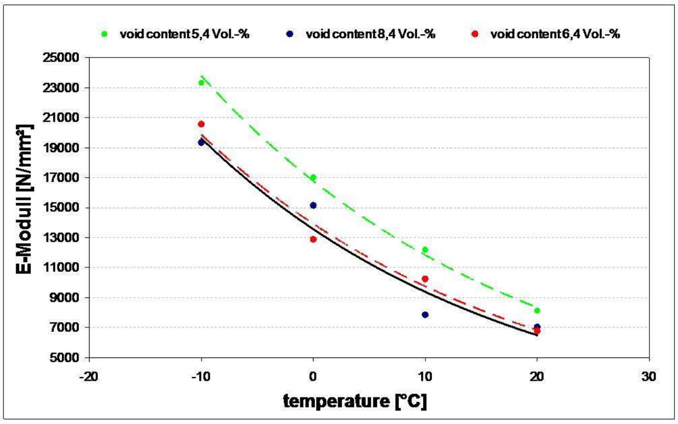

Figure 7 – E-Modulus dependent on test temperature,
Indirect-Tensile-Test; variation void content

5.6 Influence of the use of PmB

Investigations at the TU Delft [9] have clearly shown that a significant improvement of the deformation properties of the asphalt mixes can be achieved by the use of PmB in base courses. However, when employing PmB for asphalt base courses, it might be necessary to use so-called SBS polymers in order to improve the processability of the relatively hard bitumen in the base course area. Based on the positive results experienced in the Netherlands with the use of PmB for base courses, PmB was also used within the framework of this research study for the manufacture of ATS-mixes. The studies showed that the ATS-mixes with PmB had slightly lower E-Moduli (1,5 to 9,0 %) compared to the ATS-mixes with normal bitumen (Figure 8). Furthermore, it becomes evident that the difference in the E-Modulus occurs in similar dimensions for the tested temperature ranges. These results however, refer to ATS-mix tests with two selected bitumen.

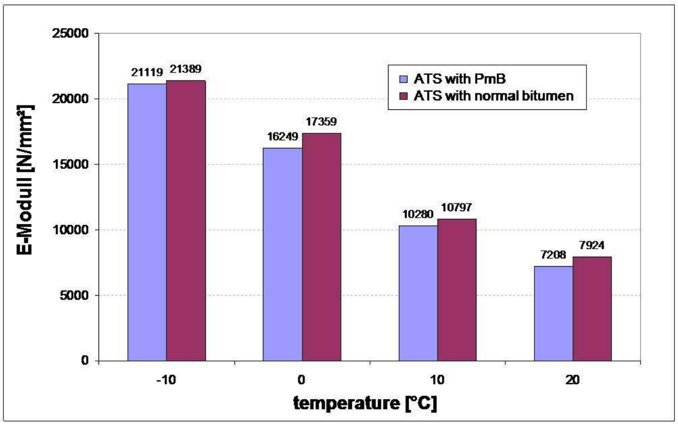

Figure 8 – E-Moduli (averages) depending on test temperatures;
ATS with normal bitumen or PmB

5.7 Comparison of test methods – ITT and 4PBT

The Four-Point-Bending-Beam-Test (4PBT) was conducted on the prismatic specimen at controlled force. The specimens were sinusodially stressed at a frequency of f = 30 Hz at controlled force.

When comparing the E-Moduli determined with the ITT and 4PBT for an identical ATS-mix it is clearly visible that the E-moduli obtained from the 4PBT are higher than those from the ITT. This applies in particular to the range of low temperatures. This is where up to 50 % higher E-Moduli with the 4PBT were identified. Concerning this comparison it is to note that among others, both tests were conducted at controlled force, however the 4PBT was performed with alternating load and the ITT with pulsating load.

In Figure 9 the E-Moduli of selected ATS-mixes (results of 4PBT and calculated according to Franken-Verstraeten) are confronted. It shows that the E-Moduli in the temperature range < 0 °C determined by means of the results of the 4PBT are significantly higher compared to the E-Moduli from the Franken-Verstraeten method. This is due to the fact that as per order the 4PBT is conducted at a frequency of 30 Hz, however the ITT is performed at only 10 Hz.

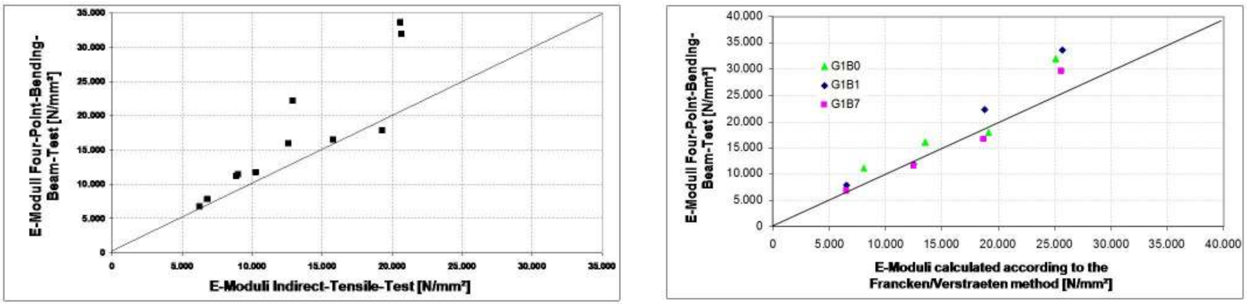

Figure 9 – Comparison of the E-Moduli – 4PBT and ITT (left);
4PBT and calculated according to Franken-Verstraeten method (right)

6 LABORATORY TEST RESULTS – FATIGUE FUNCTIONS

6.1 General

In accordance with the AL SP-Asphalt 09 [7], for the determination of the fatigue functions Indirect-Tensile-Tests were conducted for all ATS-mixes at a frequency of 10 Hz and at four different test temperatures (-10, 0, 10 and 20 °C).

The determination of the fatigue functions was performed by individual tests at three different top loads (stress amplitudes). Force-controlled, harmonic sinusoidal fatigue stress without load break at a lower stress of 0,035 N/mm^2 was applied to the specimen. For the determination of the material-specific fatigue functions, the number of load cycles to reach the point of macro cracking occurring was established. Strain based fatigue functions could be determined for all tested asphalt mixes in dependency of the initial elastic lateral strain. The number of load cycles to reach the point of macro cracking occurring was determined by means of the dissipated energy method.

6.2 Influence of binder hardness and origin

Figure 10 shows the fatigue functions for the ATS-mixes containing normal bitumen of different origin and aggregate G1. It can clearly be seen that the ATS-mixes present different fatigue behaviour. The mix with bitumen of origin B shows a significantly higher resistance to fatigue compared to the other two ATS-mixes. These results prove that the binder properties significantly influence the fatigue behaviour of asphalt.

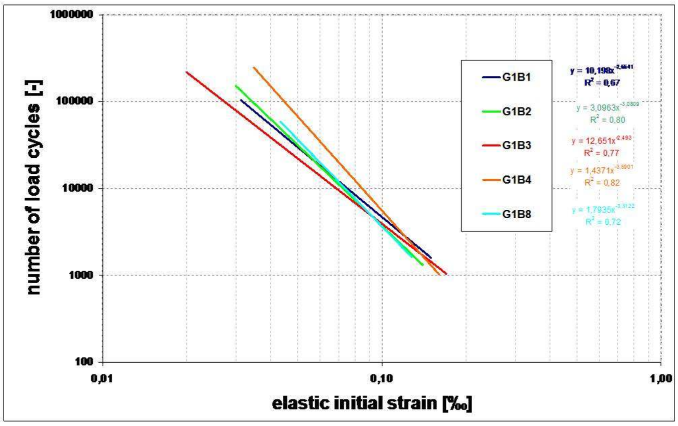

Figure 10 – Fatigue functions determined by the results of the ITT for ATS-mixes (aggregate 1 and normal bitumen 30/45 – G1B3, bitumen 50/70 – G1B1, bitumen 70/100 – G1B2, origin A – G1B1, origin B – G1B4 and origin C – G1B8)

Figure 10 equally illustrates that as expected, the resistance to fatigue of asphalt mixes diminishes, even if only slightly, with rising binder hardness. Thereby, the fatigue function of the ATS-mix with the hardest binder (bitumen 30/45 – G1B3) shows a lesser slope compared to the ATS-mix containing bitumen 70/100 (G1B2). In this context however, it should be noted that for the evaluation of the fatigue behaviour of asphalt mixes, an integral examination of the stiffness and fatigue behaviour is always required within the frame work of design calculations.

6.3 Influence of the aggregate

Figure 11 shows the fatigue functions of the ATS-mixes containing normal bitumen 50/70 and various aggregates. It becomes clear that the used aggregate has a detectable, however compared to the other tested parameters, lesser influence on the fatigue behaviour of ATS-mixes. The fatigue functions of the ATS-mixes G1B1 and G2B1 are very similar. In contrast, the fatigue function of the ATS-mix G3B1 shows a markedly steeper increase. A correlation between the fatigue resistance and the affinity of the aggregates to the binder (aggregate G1 and G3 have a better affinity compared to aggregate G2), cannot be detected from the course of the fatigue functions. Evidently, the affinity has far less influence on the properties determined within the framework of the project than previously assumed.

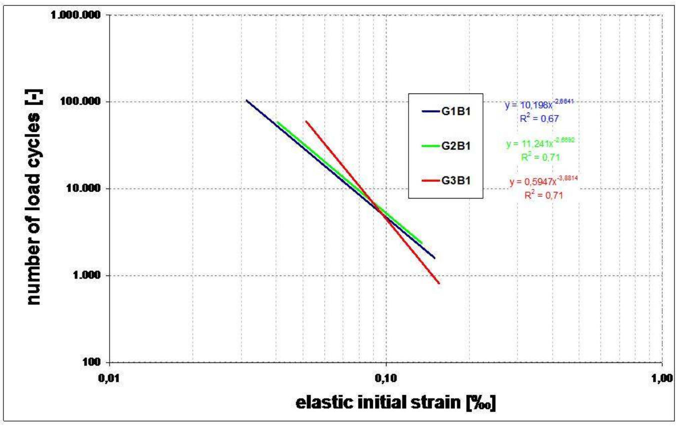

Figure 11 – Fatigue functions of the ATS-mixes containing different aggregates and normal bitumen 50/70

6.4 Influence of binder content

For ATS-mixes, an increase of binder content is generally connected to higher fatigue resistance. This fact is confirmed by the present test results (Figure 12). In this context, a continuous increase in fatigue resistance was observed with rising binder content (G1B1 → BM-content = 3,9 mass %; G1B11 → BM-content = 4,4 mass %; G1B12 → BM-content = 4,9 mass %). These results confirm the observations made by Gauthier et al. concerning the increase in fatigue resistance of asphalt mixes with rising binder content.

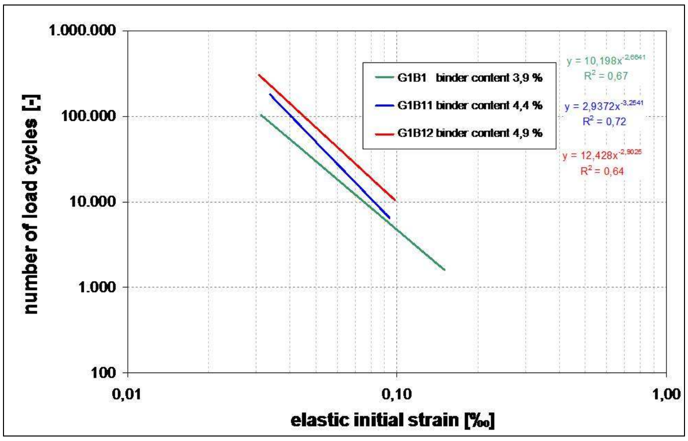

Figure 12- Fatigue functions of the ATS mixes containing aggregate 1 and normal bitumen 1 (50/70); variation binder content

6.5 Influence of void content

Generally applicable statements on the fatigue behaviour of asphalt, in dependency of existing void content or degree of compaction, can only be made to a limited extent as too few research project results exist. However, the presumption can be derived that in the case of a decrease in the void content or an increase in the degree of compaction, the fatigue resistance increases. This can be observed in the higher increase of fatigue functions. (Figure 13 (left) and (right)).

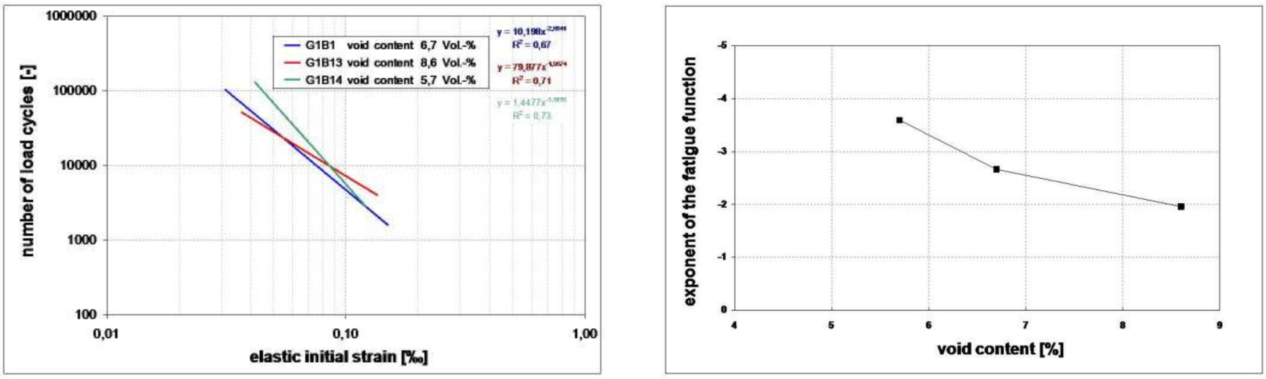

Figure 13 – Fatigue functions of ATS-mixes containing aggregate 1 and bitumen 1 (50/70); variation void content (left); comparison of the increase in fatigue functions of ATS-mixes G1; variation of void content (right)

6.6 Influence of the use of PmB

When comparing the fatigue functions of all tested ATS-mixes it must be noted that the ATS-mixes containing PmB show a higher fatigue resistance than the ATS-mixes containing conventional road bitumen. Therefore, the tested ATS-mixes containing PmB, bear higher load cycles up to the point of the micro cracking occurring, at equal strains, than ATS mixes containing normal bitumen. This can result in a longer service life of pavements for ATS-mixes containing PmB, if in addition, the stiffness (stiffness-temperature-function) of the ATS-mixes containing PmB is greater or at least equal to the stiffness of the ATS-mixes containing normal bitumen. A final evaluation of the service life of ATS-mixes with different binders can therefore only occur with the consideration of both influencing factors (stiffness-temperature-functions and fatigue function)

6.7 Comparison of test methods – ITT and 4PBT

The comparison of the fatigue functions of the ATS-mixes (G1B0, G1B1 and G1B7) determined with the Indirect-Tensile-Test (ITT) and the Four-Point-Bending-Beam-Test (4PBT) shows an identical sequence of the fatigue functions of the individual ATS-mixes (Figure 14). In this context, it can be seen for the tested ATS-mixes that there is a nearly linear coherence between the number of load cycles determined with the 4PBT and the ITT. The number of load cycles to reach the point of macro cracking occurring obtained with the 4PBT amount to around five times the number of load cycles determined with ITT. That applies on prerequisites that the strains for calculating the number of load cycles to reach the point of macro cracking are on the same level as they occur in reality on the underside of the asphalt package.

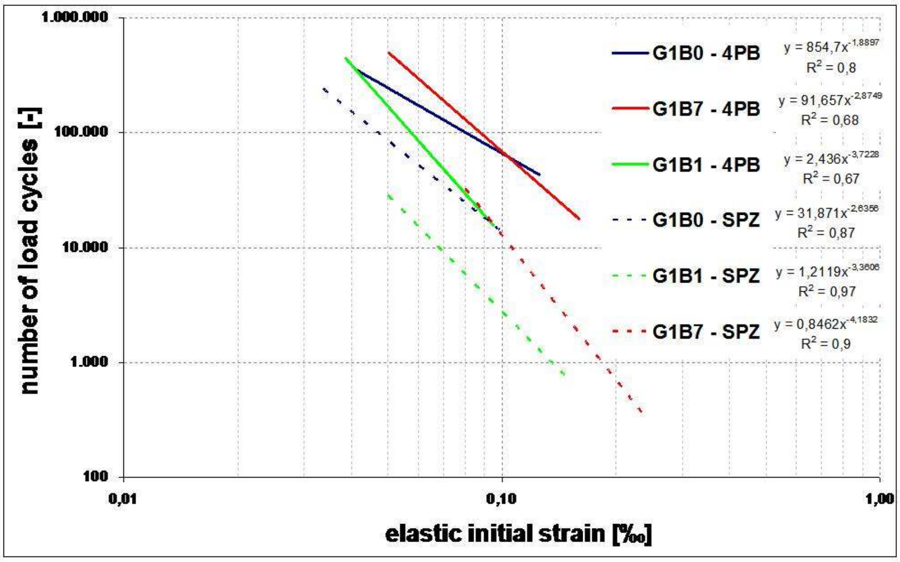

Figure 14 – Fatigue functions of the tested ATS-mixes –
4PBT (frequency of 30 Hz) and ITT (frequency of 10 Hz), 4PB = 4PBT, SPZ = ITT

7 CALCULATIONS FOR THE ESTIMATION OF THE INFLUENCE OF MATERIAL PROPERTIES ON PAVEMENT BEHAVIOUR

Calculations have been performed for the estimation of the different effects of different asphalt mix compositions and therefore also of the different material properties on the behaviour of pavements. The design program PaDesTo, version 1.2, was used for these calculations. According to the specifications of the RDO-Asphalt [2], the tensile strain on the underside of the ATS was used as design criterion for the asphalt. Based on this, it is possible to forecast the point in time (number of load cycles) of crack formation on the underside of the asphalt, and to determine the state of fatigue of the pavement.

7.1 Design input values

For the calculations, a pavement design was selected for all tested ATSATS mixes which complies with the national guideline for the standardisation of pavement structures of traffic areas, with asphalt surfacing of the construction class SV (high traffic load) and row 1. In this context, a design relevant load B of 35,2 million equivalent passes of 10 ton axle loads, with an annual traffic load increase of 3 %, from the first year of use, was assumed for the asphalt pavement. The axle load of the Federal motorway network (BAB) was applied as the axle load spectrum, and for the consideration of the annual temperature curve, the standard frequency distribution according to RDO-Asphalt [2] was applied.

The intended period of use is 30 years. The results of the Indirect-Tensile-Test in the form of the stiffness-temperature-functions were used as input values for the PaDesTo program, with regard to the material-technical description of the mixtures. A frost-proof pavement structure, in accordance with RStO 01 Table 1, column 1 (construction class SV) row 1 [1], was selected. Furthermore, the frost-susceptible class F2 and frost action zone II was specified. The gradient is located in a cut and adverse water conditions prevail in accordance with the German requirements. This results in a total thickness of 70 cm for the frost-proof pavement structure. The modulus of deformation should be a minimum of 120 N/mm² on the 36 cm thick frost blanket and a minimum of 45 N/mm² on the soil formation.

7.2 Calculation of the fatigue status

The fatigue development over a period of 30 years was calculated with the aid of experimentally determined fatigue functions for each tested ATS-mix. The permissible number of load cycles for the respective stress conditions should be determined for the largest occurring tensile bending strain in the layer. This must be calculated from the traffic load dependent maximum tensile bending strains (usually at the underside of the asphalt layers) for all asphalt temperatures and from the cryogenic tensile strains which were calculated from the cryogenic stresses at asphalt temperatures of below 0 °C.

The state of fatigue of the individual pavements is listed in Figure 15. Initially, it becomes clear that proof against fatigue is only fulfilled for the application of the ATS-mix G1B1. This means that thicker layers are required for other ATS-mixes in order to exclude structural damage in the pavements over the planned service life of 30 years.

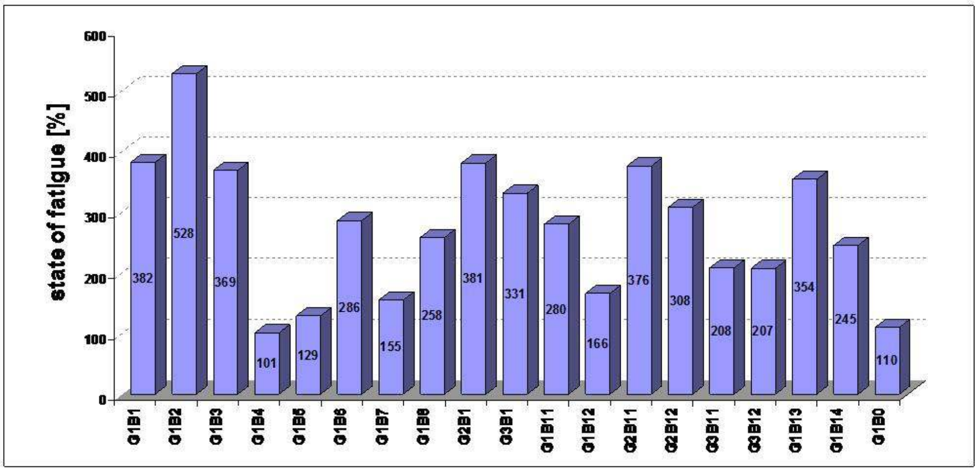

Figure 15 – State of fatigue of the various ATS-mixes

The research shows that the bitumen properties of the asphalt mixes can have a significant influence on the fatigue behaviour, and therefore on the service life of pavements, on the one hand due to origin, and on the other hand due to the addition of polymers (Figure 16 (left) and (middle)).

Furthermore, it becomes clear that the required binder specifications in the current German Guidelines and the respective tests are obviously not sufficient to characterise binders in such a way that design relevant asphalt properties can be achieved accurately. The results make it clear that the use of binders specified as “equivalent” (e.g. 50/70) can produce a very different fatigue behaviour of the ATS-mixes at otherwise equal parameters, such as grading curve or type of aggregate. For this reason it is only possible to record the mechanical behaviour of asphalt mixes and to design pavements respectively within the framework of an analytical design in the context of suitable performance-orientated laboratory tests (e.g. Indirect-Tensile-Tests).

Despite small differences in respect of the E-Moduli, it became particularly apparent that the fatigue behaviour of the mixes differ significantly for the tested ATS-mixes containing normal bitumen and PmB. Figure 16 (middle) illustrates that the pavement’s state of fatigue is significantly reduced due to use of PmB in the tested ATS-mixes, and thus a markedly longer service life of the pavement can be expected when using PmB in the ATS compared to using normal bitumen. Research on the significant improvement of fatigue behaviour of asphalt pavements through the use of PmB, conducted by Liu and Scarpa [9] confirms this. In all cases, design calculations are highly recommended for the estimation of the effects on the service life of pavements by the use of PmB.

As expected, the influence of the aggregate on the fatigue behaviour of pavements for the tested asphalt variants is relatively low (Figure 16 (right)). It must be noted conclusively that based on the present calculation results, the factors of safety for fatigue conditions currently contained in the RDO-Asphalt, appear to be too conservative. For this reason, especially these safety factors must be revised and if necessary redefined by the means of further calibration calculations on standard pavement structures of the RStO [1].

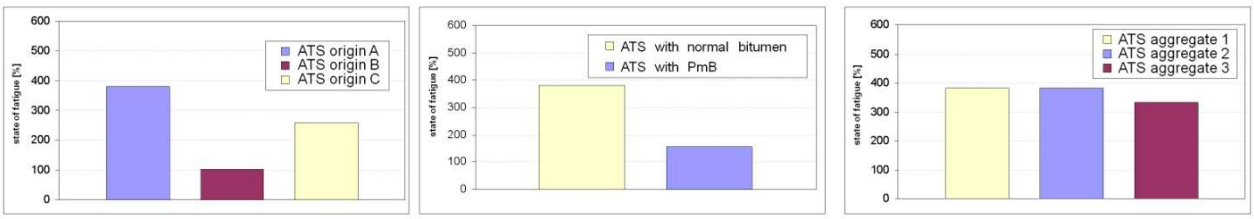

Figure 16 – State of fatigue of ATS-mixes using binders 50/70 of different origin (left); state of fatigue of ATS-mixes using normal bitumen 50/70 and PmB (middle); state of fatigue of ATS-mixes using normal bitumen 50/70 and different aggregates (right)

8 SUMMARY

In summary it can be stated that the binder properties of the tested asphalt mixes have a significant influence on the fatigue behaviour of the asphalt-mixes. Furthermore, it becomes apparent that the required binder specifications and respective tests, as currently required in the German guidelines, do not appear to be sufficient to characterise the binders used here, in order to accurately influence the mechanical behaviour of asphalt. The tests have made it clear that the use of binders specified as “equivalent” (e.g. 50/70) can produce very different fatigue behaviour of the ATS-mixes at otherwise equal parameters, such as grain size distribution or aggregate mixes. For this reason it was only possible to record the mechanical behaviour of the asphalt mixes and to design pavements respectively within the framework of an analytical design in the context of suitable performance-orientated laboratory tests (e.g. Indirect-Tensile-Tests). In this context, it must be mentioned that based on the present calculation results acquired with the PaDesTo program, the factors of safety currently contained in the RDO-Asphalt appear to be too conservative for the fatigue functions. For this reason, it is recommended that the factors of safety are reviewed within the framework of future research studies by further calibration calculations and if necessary, redefined.

Furthermore, the research has shown that the use of PmB can improve the fatigue behaviour of asphalt. The results proved that positive effects in respect to service life of pavements could be achieved by the use of PmB and also for ATS-mixes for highly stressed asphalt pavements.

REFERENCES

1. FGSV (2001): Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen (RStO), ergänzte Fassung von 2001, Köln.
2. FGSV (2009/1): Richtlinien für die rechnerische Dimensionierung des Oberbaues von Verkehrsflächen mit Asphaltdeckschicht (RDO-Asphalt) (Entwurf), Köln.
3. Werkmeister, S.; Lipke, S.; Wellner, F. (2009): Prognose der Restnutzungsdauer von Asphaltbefestigungen – Ergebnisse von Versuchstrecken, Straße und Autobahn, Heft 4, 2009.
4. Francken, L.; Verstraeten, J. (1974): Methods for predicting moduli and fatigue laws of bituminous road mixes under repeated bending, Transportation Research Record 515, S. 114-123, Washington D. C.
5. Gauthier, G.; Bodin, D.; Chkir, R. (2008): Stiffness and Fatigue Properties of Asphalt: Effect of the Bitumen type and the Bitumen content. Eurasphalt & Eurobitume Congress, May 21-23, Copenhagen, Denmark.
6. Werkmeister, S.; Wellner, F. (2004): Die Untersuchung des Ermüdungsverhaltens von Asphaltgemischen mit dem dynamischen Spaltzugversuch im Rahmen einer analytischen Bemessung. Bitumen, Heft 3.
7. FGSV (2009): Arbeitsanleitung zur Bestimmung des Steifigkeits- und Ermüdungsverhaltens von Asphalten mit dem Spaltzug-Schwellversuch als Eingangsgröße in die Dimensionierung (AL Sp-Asphalt 09), Köln.
8. Liu, X.; Scarpas, A. (2009): 3D finite element modelling of polymer modified asphalt base course mixes. Advanced Testing and Characterization of Bituminous Materials, Conference proceedings pp. 939-948, CRC Press/Balkema.
9. Kiehne, A. (2008): Rechnerische Dimensionierung von Verkehrsflächenbefestigungen in Asphaltbauweise – Entwicklung und Umsetzung eines Verfahrens. Manuskript zur Dissertation, TU Dresden (unveröffentlicht).
10. Hess, R. (1998): Kalibrierung von Verhaltensmodellen für das Straßenerhaltungsmanagement. Diplomarbeit, Institut für Verkehrswirtschaft, Straßenwesen und Städtebau, Fachgebiet Konstruktiver Straßenbau der Universität Hannover, Hannover, 1998, Deutschland.