Effect of Different Polymer-modified Bitumen of the same Sort on the Fatigue Behavior of Asphalt

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ABSTRACT: The use of polymer-modified bitumen of the same sort from different manufacturers can lead to, as experience shows, different properties of the asphalt mixes produced with it. These differences shall be shown by means of the fatigue behavior of asphalt mixes using the Cyclic Indirect Tensile Test on Mastic Asphalt and Asphalt Concrete. For this purpose, polymer-modified bitumen 25/55-55 A and 10/40-65 A from different manufacturers were analyzed using the Softening Point Ring and Ball, Penetration, Force-Ductility and Elastic Recovery tests. In addition, chemical properties like chromatography or infrared-spectroscopy were investigated. Afterwards, the bitumen was used for the asphalt mix production for dynamic testing. The above- mentioned asphalt mixes were always used with a constant composition. Test results from the Cyclic Indirect Tensile Test with or without cryogenic tensions, as well as fatigue curves of different asphalt mixes are presented and analyzed in dependence on the bitumen properties. Furthermore, the effects of changes in bitumen properties during oxidative and/or thermal stress in the laboratory are shown. These specific stresses shall represent possible changes of the asphalt mixes during the production process and during storage in practice. The dimensions of the results, as well as the influences on the properties of different polymer-modified bitumen, were indicated in the performed experiments.

KEY WORDS: Fatigue Behavior, Cyclic Indirect Tensile Test (CITT), Polymer-modified bitumen

1 MOTIVATION

Bitumen manufacturers follow different approaches to realize a high quality and durable polymer-modified bitumen (PmB). However, during investigations in the laboratory, it has been noticed that the same type of PmB, but from different manufacturers, shows different properties.

Differences in properties occur, for example, during the force-ductility test. As required at the time of delivery, the conventional binder tests such as penetration and softening point ring and ball, show differences only in small ranges.

Whether, and to what extent these differences in parameter values have an influence on the performance properties of asphalt in practice, is largely unknown.

Results from investigations by Hase and Oelkers (2006) show that there may very likely be a correlation between the rheological behavior of PmB and the deformation behavior of the corresponding asphalt in the Uniaxial Cyclic Compression Test. Investigations done by

Büchler et al. (2008) show the correlation between the values of bitumen parameters from the dynamic shear rheometer and the force-ductility test with respect to low-temperature properties and also with respect to the fatigue properties of stone mastic asphalts. It is against this background that the following described results from investigations at the Karlsruhe Institute of Technology, Institute for Highway and Railroad Engineering (Roos et al. 2009) have been achieved. This was done by analyzing and interpreting the fatigue properties of mastic asphalts and asphalt concretes with different PmB from different manufacturers using the Cyclic Indirect Tensile Test.

2 CYCLIC INDIRECT TENSILE TEST (CITT)

2.1 Test method

The Cyclic Indirect Tensile Test is used to determine the stiffness and fatigue behavior of asphalts at different temperatures and frequencies. Here a sinusoidal loading is applied vertically to a cylindrically shaped specimen (Fig. 1).

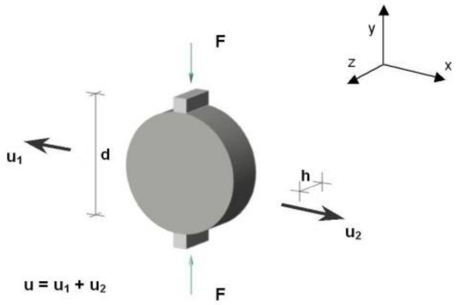

Figure 1: Principle of the Cyclic Indirect Tensile Test (AL-SP – Asphalt 2009)

Due to these forces a two axial stress condition occurs in the specimen: In the direction of loading (vertical) a compression stress, which varies along the specimen axis, develops. In the horizontal direction a tensile stress is induced. This stress is nearly constant in the central section at the vertical axis of the specimen and is the main cause of material fatigue and the failure of the specimen.

During the test the effective force as well as the horizontal strain are recorded. These are measured with displacement transducers that are placed centrally and are diagonally across one another on the surface of the specimen. The horizontal deformations at the specimen centre can be calculated based on these measurements. The loading cycle at which fatigue occurs is defined as N_{Macro} and this is the stage of the fatigue test at which macro cracks start to be observed in the specimen. After this stage cracks develop fast and eventually the specimen fails completely.

A method to determine N_{Macro}, which is based on the concept of dissipated energy, was developed by Hopmann et al. (1989). Here the so-called dissipated „Energy Ratio“ ER is defined and it is calculated as the product of the load cycle N and the for the respective load cycle calculated stiffness modulus |E(N)|:

$$ER(N) = |E(N)| \cdot N \quad [MPa] \tag{1}$$

with ER(N) = Energy Ratio [MPa]; |E(N)| = Stiffness modulus at the respective load cycle N [MPa]; N = number of load cycle [-].

The stiffness modulus |E| is calculated according to the following formula which is based on the horizontal strain of the associated specimen as well as the applied force at that time:

$$|E| = \frac{\Delta F \cdot (0{,}274 + \mu)}{h \cdot \Delta u} \quad [\mathrm{MPa}] \qquad (2)$$

where ΔF = difference between the minimum and maximum force [N]; μ = Poisson´s ratio [-]; h = specimen height [mm]; Δu = difference between the minimum and maximum horizontal deformation of the specimen per load cycle [mm].

If ER(N) is represented as a function of N, the load cycle at which fatigue takes place can be determined for the criteria macro cracking N_{Macro} at the maximum of ER(N). From these analyses further parameters can be determined. The initial elastic horizontal strain $\varepsilon_{el,in}$ is calculated from the average elastic deformations at load cycles 98 to 102 and the respective stiffness modulus |E| is determined.

2.2 Test conditions and specimens

The Cyclic Indirect Tensile Test is performed according to the AL-SP – Asphalt 09 (2009) guideline in a temperature range of -15 to +20 °C. Fatigue functions are determined for dimensioning at +20 °C. On the basis of comprehensive investigations with the Cyclic Indirect Tensile Test a testing temperature of +10 °C was chosen for mastic asphalt specimens, the asphalt concrete was tested at +20 °C.

Table 1: Test conditions and specimen dimensions for the Cyclic Indirect Tensile Test for different asphalt types.

Parameter	Unit	Asphalt Concrete 0/22	Mastic Asphalt 0/11
Specimen height	mm	60	40
Specimen diameter	mm	150	100
Test temperature	°C	+20	+10
Frequency	Hz	10	10
Stress difference between max. and min. stress	MPa	0.7	0.7

For these experiments performed with the Cyclic Indirect Tensile Test, the mastic asphalt specimens were obtained by taking cores from roller compacted slabs. The mastic asphalt specimens were compacted manually in a cylindrical form. The respective specimen dimensions and test conditions can be seen in Table 1.

3 COMPOSITION OF ASPHALT MIXES AND PROPPERTIES OF POLYMER-MODIFIED BITUMEN

For these tests only PmB were used. For each of asphalt concrete 0/22 (22 mm particle top size) and mastic asphalt 0/11 (11 mm particle top size), 6 asphalt types were produced (Roos et al. 2009) with Bitumen 10/40-65 A and 25/55-55 A from four different manufacturers. The composition of the asphalts according to ZTV Asphalt-StB 01 (2001) can be seen in Table 2 and the allocation of PmB and manufacturers to the asphalts are also shown in Table 2.

To maintain a constant grain size distribution, the aggregate mixtures were prepared in exactly the same manner. Due to the use of PmBs of various manufacturers, void contents of the asphalt concretes and static die penetration depths of mastic asphalts varied in small ranges and resulted in the selection of the same bitumen volume. The twelve asphalts types were selected, such that every manufacturer was represented at least once with every product (Table 3).

Table 2: Composition of the asphalt mixes according to ZTV Asphalt-StB 01 (2001)

Type of Asphalt			Mastic Asphalt 0/11	Asphalt Concrete 0/22
Type of Aggregate	Filler 0/0.09	[-]	Limestone	Limestone
	High-quality sand 0/2	[-]	Moraine	Moraine
	Natural sand 0/2	[-]	Moraine	-
	Grain class 2/5	[-]	Moraine	Moraine
	Grain class 5/8	[-]	Moraine	Moraine
	Grain class 8/11	[-]	Moraine	Moraine
	Grain class 11/16	[-]	-	Syenite
	Grain class 16/22	[-]	-	Syenite
High-quality Crushed Sand/Natural Sand Ratio		[-]	2:1	1:0
Fraction of	Grain class < 0.09	[wt.-%]	26.4	6.5
	0.09 – 2.0	[wt.-%]	23.6	20.5
	> 2.0	[wt.-%]	50.0	73.0
Maximum Density of Aggregates		[g/cm^3]	2.668	2.693
Bitumen Sort/Volume	10/40-65A	[wt.-%]	7.3	4.3
	25/55-55 A	[wt.-%]	7.0	4.2
Void contents of the types	10/40-65A	[vol.%]	-	4.3 to 5.0
	25/55-55 A	[vol.%]	-	4.6 to 5.8

Table 3: Asphalt types – the allocation of PmB and manufacturers to the asphalts as well as the numbering of the options

Asphalt Type and Sort	Bitumen Sort	Bitumen Manufacturer **Asphalt Type No.**			
		1	2	3	4
Mastic Asphalt 0/11	10/40-65 A	**1**	**2**	**3**	
	25/55-55 A		**4**	**5**	**6**
Asphalt Concrete 0/22	10/40-65 A	**7**		**8**	**9**
	25/55-55 A	**10**	**11**		**12**

Table 4: Selected bitumen features or properties at delivery

Property	Unit	Bitumen Sort	10/40-65 A				25/55-55 A			
		Manufacturer	1	2	3	4	1	2	3	4
		Grade	0 (Delivered State)				0 (Delivered State)			
Needle Penetration	0,1 mm	DIN EN 1426	26	35	35	28	30	46	44	45
Softening Point Ring and Ball	°C	DIN EN 1427	74.0	67.2	64.4	63.8	58.5	56.8	58.6	62.0
Force Ductility, Deformation	J	TL PmB/ DIN 52013	0.813	0.824	1.135	0.866	0.674	0.373	0.516	0.749
Force Ductility, Maximum Force F_{max}	N	TL PmB/ DIN 52013	14.1	6.3	8.9	8.4	6.9	4.7	3.5	2.4
Force Ductility Deformation at 5 and 10 °C	J/cm^2	DIN EN 13589/ 13703	3,89	6,43	7,44	7,38	3,88	2,92	4,87	10.5
Force Ductility, Maximum Force F_{max} at 5 and 10 °C	N	DIN EN 13589/ 13704	113.9	56.9	75.4	90.3	179.0	112.3	114.6	80.1
Elastic Recovery 20 cm/ 25 °C	%	DIN EN 13598	66	74	78	78	57	54	77	83

Selected features or properties of PmB at delivery can be seen in Table 4. The values of the standard parameters for needle penetration and softening point ring and ball show no discrepancies; all the PmB parameters comply with the specifications in the guidelines.

The partly big differences for the respective parameters that were obtained for a PmB sort, e.g. for the force-ductility test, are due to the different compositions and interlacing of the polymers and the different base bitumen that was used. This was confirmed by gel permeation chromatography and infrared-spectroscopy analyses.

4 LOADING OF ASPHALT MIXES IN THE LABORATARY

In further investigations to determine the fatigue properties of asphalt mixes using modified bitumen properties, the asphalt mixes were purposefully loaded. The aim was not to simulate the aging of the asphalts over a specific time on site, but to investigate loading of asphalts at different manufacturing and storage conditions, as well as during transportation. Different loading was chosen to give conditions as close as possible to common practice and so that the specific technological manufacturing methodology of the asphalts was considered:

After mixing (stage 1) according to the Technical Standards the mastic asphalts were exposed to a temperature of 250 °C and low rotation speeds in a sealed mixer to prevent air entering it for a time of

- 60 minutes in stage 2 and
- 165 minutes in stage 3.

The asphalt concretes were granulated after mixing and were put into a warming oven on a gauze at 180 °C at a defined air exchange (11 m^3/h) and were exposed for a time of

- 120 minutes in stage 2 and
- 180 minutes in stage 3.

Thus the exposure of mastic asphalt can be seen as predominantly thermal and that of the asphalt concrete as oxidative and thermal.

The PmB was re-extracted from the asphalt mixes after mixing stage 1 and from each of the mixes after mixing stages 2 and 3. Different bitumen parameters were determined with tests such as e.g. penetration, softening point ring and ball, force-ductility and elastic recovery. Selected results are shown in the diagrams of the following chapter.

5 RESULTS OF CITT AND DETERMINATION OF CORRELATIONS WITH BITUMEN PARAMETERS

To determine the fatigue properties of the asphalt sorts, the Cyclic Indirect Tensile Test was applied in stage 1 (after mixing) and stage 3 (after extended exposure). For selected options the test was applied additionally in stage 2 (after exposure).

5.1 Asphalt concrete

For the Cyclic Indirect Tensile Test of asphalt concretes, a uniform minimum stress of 0,035 MPa, as well as a stress difference between the minimum and maximum stress of 0,7 MPa was chosen.

The load cycle N_{Macro} after stage 1, i.e. after the mixing, showed, as expected, lower values for the types with 25/55-55 A. These were in the range of 770 to 2,426 load cycles. The types with 10/40-65 A achieved 5,460 to 7,576 load cycles (Figure 2). This range in load cycles amongst the PmB sorts shows that the implementation of PmB from different manufacturers has an influence on the results of fatigue tests and thus also on the fatigue properties of asphalt concrete.

The thermal and oxidative exposure in the stages 2 and 3 led to brittleness which was shown e.g. by the bitumen tests softening point ring and ball and by the higher maximum force F_{max} that was achieved during the force-ductility test. The exposure led to an increase in load cycles in all but one sort. The load cycle range for the sorts with 10/40-65 A was 4,351 to 9,455 and for 25/55-55 A sorts it was 1,085 to 3,946. At stage 3 of sort 8 the load cycle dropped and the bitumen tests also showed discrepancies: The softening point in stage 3 lay at 99.2 °C which is an indication for strong brittleness of the PmB and which evidently leads to worsening fatigue properties.

Even though there is a known variance of the single values during dynamic testing for fatigue properties, a clear differentiation of the results and also of single values between the 3 stages, with an average coefficient of variation of 23%, is possible (Figure 2). This was the case for all sorts except type 7.

The change in load cycles from stage 1 to stage 3 differed for each sort. The load cycles in stage 3 are dependent on the changed properties of the exposed PmB. Thus every PmB reacts with a different intensity to the thermal and oxidative exposure due to the specific composition of the different PmB which have different standards. Thus every PmB shows a varying "exposure sensitivity" which influences the asphalt properties differently.

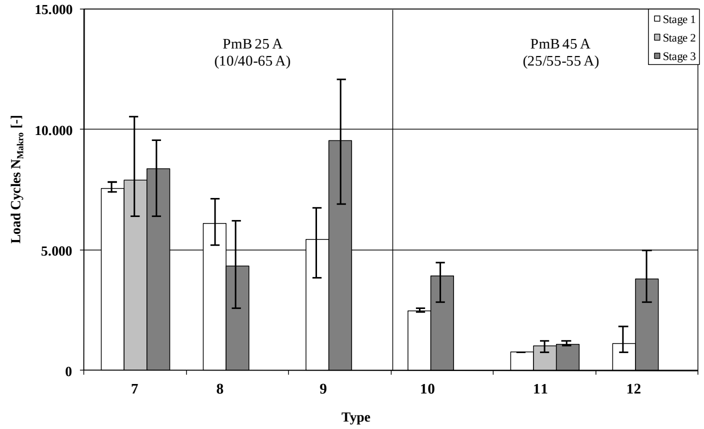

Figure 2: Arithmetic averages of the load cycles N_{Macro} with ranges of the three single values for the asphalt concrete types in the stages 1 to 3 ($\Delta\sigma = 0.7$ MPa)

As with the differently achieved load cycles in stage 1 and their changes in stages 2 and 3, as expected, changes were observed for the initial elastic strain and for the stiffness modulus. The initial elastic strains decreased at the same stress while proceeding from stage 1 to stage 3 with an average of 0.026‰. Type 7 remained virtually constant. The small differences of the load cycles and the stiffness modulus between the stages 1 to 3 of this type result from the distribution of the test results (Figure 2 and Table 5). The used PmB has a distinct influence on the stiffness as is shown by the range of the stiffness modulus in stage 1. Bitumen 25/55-55 A for example, has values from 11,036 to 16.103 MPa.

Table 5: Average values for the initial elastic strains and the corresponding stiffness modulus of the asphalt concrete types in the stages 1 to 3

	Initial elastic strain [‰]			Stiffness modulus [MPa]		
Type	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
7	0.087	0.085	0.092	16,103	16,237	15,270
8	0.122	-	0.114	11,411	-	12,264
9	0.126	-	0.096	11,036	-	14,608
10	0.126	-	0.116	10,992	-	12,042
11	0.217	0.178	0.166	6,384	7,778	8,415
12	0.196	-	0.132	7,187	-	10,574

- not investigated

Due to the exposure of the asphalts and the accompanying brittleness in the stages 2 and 3, the initial elastic strains decreased and the values of the stiffness modulus increased. As with the load cycles, the changes of these parameters due to exposure were dependent on the "exposure sensitivity" of each PmB.

To determine influences of the PmB properties on the results of fatigue tests, amongst other tests, the maximum force F_{max} was obtained from the force-ductility test. Wear of the PmB was specially noticed when the maximum force F_{max} was increased. With type 8 described above, where the load cycle number dropped in stage 3, the largest increase in maximum force from stage 1 to stage 3 could be observed. This force increased more than fourfold. For all stages no correlation could be found between the maximum force F_{max} from the force-ductility test and the load cycle number N_{Macro} (Figure 4).

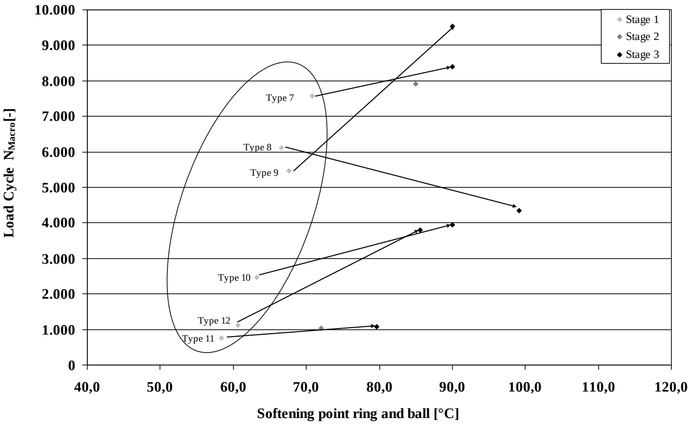

Figure 4 Correlation between the maximum force F_{max} from the force-ductility test and the load cycle number N_{Macro} of the Mastic Asphalt types in the stages 1 to 3

If only the results of stage 1 are considered (enclosed points) a correlation with a coefficient of determination of R^2 = 74.5 % is obtained.

The change of the two parameters of the types during all the stages is shown by the arrows in figure 4. Here it can be clearly seen that every sort changes differently in accordance with the different standards and the varying exposure sensitivities. Further loading of the asphalts beyond stage 3 and the determination of the load cycle number N_{Macro} is theoretically possible, but in practice, investigations of the bitumen properties become increasingly difficult. Experience has however shown that the load cycle numbers decrease because the asphalt becomes increasingly brittle and thus the fatigue properties worsen; i.e a specific curve with the maximum load cycle number that can be endured, can be drawn.

A similar result is observed when trying to obtain a correlation between the values from the softening point ring and ball test and the load cycle number N_{Macro} for all stages. If only stage 1 is taken into consideration, a correlation with a coefficient of determination of R^2 = 95.3 % can be observed.

5.2 Mastic asphalt

For the Cyclic Indirect Tensile Test of mastic asphalts, specific cryogenic stresses were taken into consideration as the respective minimum stress. These were determined by initially performing cooling tests. For this reason there were different minimum and therefore also different maximum stresses for the respective types and stages due to the chosen constant stress difference of 0.7 MPa.

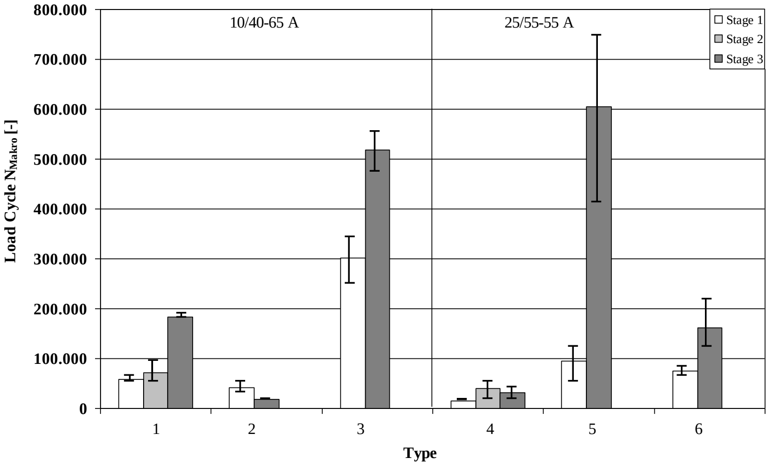

Figure 5: Arithmetic averages of the load cycles N_{Macro} with ranges of the three single values of the mastic asphalt types in the stages 1 to 3 ($\Delta\sigma = 0.7$ MPa with cryogenic minimum stress)

The load cycle numbers N_{Macro} of stage 1 for the types with Bitumen 10/40-65 A were in the range 41,548 to 301,780 and those for the types with 25/55-55 A were in the range 14,515 to 94,594 (Figure 5). Thus a differentiation of the PmB sorts according to the amount of load cycles, is not possible. This is due to the specific properties of the respective PmB and amongst other due to the different occurring minimum stresses. Due to the thermal exposure, the asphalt went brittle and higher cryogenic stresses occurred during the cooling tests. This led to higher minimum and maximum stresses in the stages 2 and 3. An increase in load cycle numbers was observed for all types except types 2 and 4. The highest increase occurred with type 5. Here the load cycle number increased more than fivefold. Also in the case of the mastic asphalts the load cycle numbers changed differently for the stages 1 to 3.

Due to the exposure of the asphalts, the initial elastic strains and the stiffness modulus changed according to the exposure sensitivity of the PmB: The strains of mastic asphalts in stage 1 were between 0.093 and 0.126 ‰ and decreased with an average of 0.016 ‰ in stage 3 (Table 6).

Table 6: Average values of the initial elastic strains and the associated stiffness modulus of the mastic asphalts in the stages 1 to 3

	Initial elastic strain [‰]			Stiffness modulus [MPa]		
Sort	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
1	0.093	0.087	0.071	15,710	16,644	20,383
2	0.106	-	0.099	13,645	-	14,706
3	0.093	-	0.073	14,641	-	19,706
4	0.126	0.115	0.106	11,624	12,511	13,654
5	0.100	-	0.090	14,759	-	16,598
6	0.099	-	0.080	14,906	-	18,049

- not investigated

On average the stiffness modulus of the types with Bitumen 10/40-65 A in stage 1 was 14,665 MPa and that for 25/55-55 A was 13,763 MPa and increased with an average of 2,969 MPa in stage 3. The average values for the harder PmB sorts had a higher value for the stiffness modulus but when looking at the single values, the types could not be differentiated according to the PmB, as was the case with the mastic asphalts (Table 6).

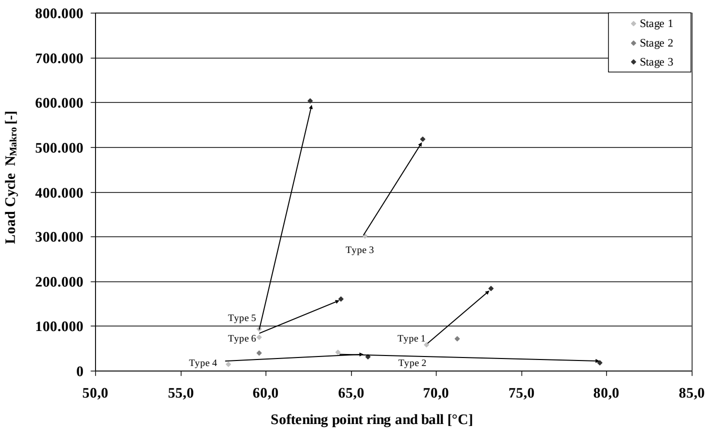

Figure 6: Correlation between the softening point ring and ball and the load cycle number N_{Macro} of the mastic asphalt types in the stages 1 to 3.

No correlation could be found between the softening point ring and ball and the load cycle number N_{Macro} for all stages (Figure 6). The same findings were obtained during investigations with the maximum force F_{max} from the force-ductility test. If even only stage 1, which showed good correlations in the results of the Mastic Asphalts, is considered, no correlation can be found.

The changes of some types during the loading stages are shown in figure 6 by means of arrows. Here it is clearly seen that each sort changes differently and in accordance with different standards and different exposure sensitivities. There is also the possibility of loading the asphalts beyond stage 3 and determining the load cycle number N_{Macro}. However, with this procedure, investigations for bitumen properties become increasingly difficult. Experience shows that therefore a decrease in load cycle numbers can be expected.

The results presented here for the asphalt concrete and the mastic asphalt types were done by respectively choosing one stress condition (stress difference) at one temperature and therefore they represent only one pair of values for, e.g. the fatigue function. The results are strongly influenced by the respective stiffness modulus of the asphalts with the specific PmB under the chosen conditions.

6 CONCLUSION OF THE FINDINGS

The investigations show that the PmB sorts from different manufacturers give a wide range for the standard parameters that give the properties of bitumen as well as for the fatigue properties of asphalts. Therefore it is very important to at least consider the properties of the different products with respect to the mechanical characteristic “fatigue” when choosing a suitable bitumen.

For the range of the temperatures used in this investigation, the oxidative or thermal and oxidative exposure of the asphalts has the effect of increasing the load cycle numbers and the stiffness. Also, smaller strains occur at the same stress difference. These results show that the fatigue property of the exposed asphalts improves. However, in order to give a detailed description of the fatigue properties of the asphalts in the future, it will be necessary to determine fatigue functions and stiffness modulus-temperature functions for all thermal or thermal and oxidative exposure stages.

The change in load cycle numbers, stiffness and strains due to exposure is dependent on the typical exposure sensitivity of the respective PmB. This is shown by the detailed investigations in each of the loading stages.

Thus the comparison of selected bitumen parameters with the results of the Cyclic Indirect Tensile Test gives no correlation for all stages. Only in the case of the Mastic Asphalt sorts that were not exposed, good correlations were achieved between the softening point ring and ball values and the maximum force F_{max} from the force-ductility test with the load cycle numbers N_{Macro}. It can be assumed that other bitumen properties or characteristics, that were not investigated here, have an influence on the fatigue properties, such as for example the affinity between bitumen and aggregate.

The different stiffnesses of an asphalt sort, which are obtained when choosing a PmB manufacturer, need to be considered purposefully during dimensioning. The investigations have shown that the same applied PmB sort from different manufacturers gives different bitumen and fatigue properties.

REFERENCES

Büchler, S., Mollenhauer, K., Renken, P., 2008. *Einfluss von modifiziertem Bitumen auf die Kälte- und Ermüdungseigenschaften von Asphalt und deren Veränderung während der Nutzungsdauer*. Bundesministerium für Verkehr, Bau- und Wohnungswesen (Hrsg.), Schriftenreihe „Forschung Straßenbau und Straßenverkehrstechnik“, Heft 991, Bonn, Germany.

Hase, M., Oelkers, C., 2006. *Gibt es Qualitätsunterschiede bei polymermodifizierten Bindemitteln gleicher Sorte?* Straße und Autobahn, Nr. 2, Cologne, Germany.

AL-SP – Asphalt 09, 2009. *Prüfverfahren für die Dimensionierung von Asphaltbefestigungen: Arbeitsanleitung zur Bestimmung des Steifigkeits- und Ermüdungsverhaltens von Asphalten mit dem Spaltzug-Schwellversuch als Eingangsgröße für die Dimensionierung von Asphaltbefestigungen (*. Forschungsgesellschaft für Straßen- und Verkehrswesen (Hrsg.) Bearbeitungsstand: 20.05.2009, Cologne, Germany.

Hopman, P., Kunst, P., Pronk, A., 1989. *A Renewed Interpretation Model for Fatigue Measurement. Verification of Miner’s Rule.* 4th Eurobitume Symposium, 4-6 October 1989,.; Vol. 1; pp. 557-561, Madrid, Spain.

Roos, R., Karcher, C., Wittenberg, A., Plachkova, P., 2009. *Zusammenhang des Wertes für die Elastische Rückstellung von zurückgewonnenem polymermodifizierten Bindemittel und den Gebrauchseigenschaften des Asphaltmischgutes zur Schaffung eines Bewertungsmaßstabes.* FE 07.213/2006/EGB, Schlussbericht, Karlsruhe, Germany.

ZTV Asphalt-StB 01, 2001. *Zusätzliche Technische Vertragsbedingungen und Richtlinien für Asphalt im Straßenbau*. Forschungsgesellschaft für Straßen- und Verkehrswesen, Cologne, Germany.