Modification of binder properties of asphalt from delivery condition to paving

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ABSTRACT

The determination of binder properties and possible modifications of them during the mixing process, transport and paving is part of the research project FE 07.0253/2011/ERB „Representative determination of performance-relevant properties of asphalt as base for new conditions of contract".
Therefor asphalt (surface, binder and base course asphalt) was sampled in three phases at 21 highway projects spread over Germany.The first phase represents the design of asphalt mixture. Initial type testing wih the starting material (aggregates and binder) were repeated. In addition, the binder was examined in the delivered condition(directly from the refineries). In the second phase the large scale production of asphalt will be investigated. For this purpose, asphalt produced at the asphalt mixing plant was taken during paving. Following in the third phase the paved asphalt course was sampled. Cores with different diameters were taken at the points where the examined asphalt from the second phase was paved.
Different performance tests were carried out on the extracted binder of each phase and course. The results of the tests in the dynamic shear rheometer (phase angle, complex shear modulus (DSR), deformation behavior of binders (MSCR-Test)) and possible differences between the individual phases and their effects will be explained in this paper.

Keywords: Performance testing, Physical properties, Rheology, Viscosity

1. INTRODUCTION

In the scope of the research project 07.0253/2011/ERB "Representative determination of the performance-relevant asphalt properties as the basis for new contractual conditions" [1], 21 examination routes were tracked from the asphalt mix design to the finished layer. To consider regional differences in the rock occurrence, the binder properties and the building materials and building material mixtures currently on the market, the 21 examination routes were distributed across Germany. The surface course asphalt, binder course asphalt and base course asphalt were renewed in all construction measures.

To consider possible changes to the performance-relevant indices of the asphalt or binder during mixing, transport and pavement, each examined route was sampled in three phases (figure 1).

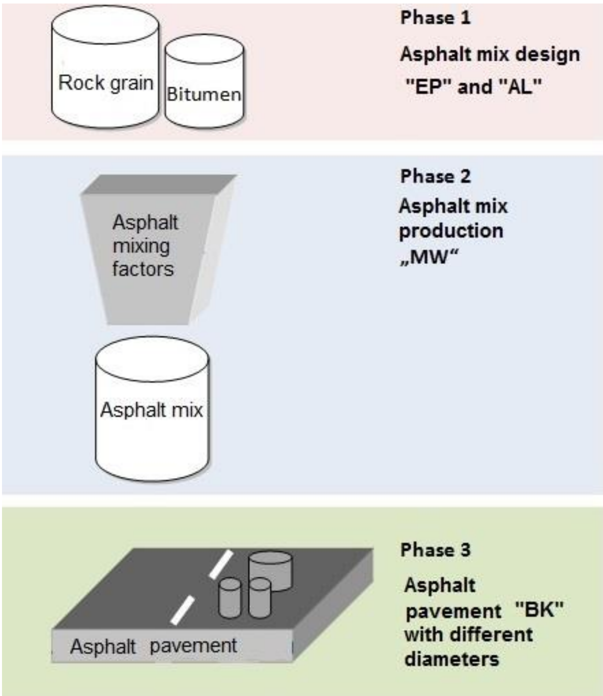

Figure 1: Examination phases [1]

Phase 1 represents the asphalt mix design. For this, a "tracking" of the first inspection "EP" with the starting materials (rock grains and binders) took place in the scope of the research project. Additionally, the binder was examined in the delivery condition "AL" (right from the refineries). In phase 2, the large-scale asphalt mix production was examined. For this, the asphalt mix "MW" produced at the asphalt mixer was taken during pavement. Afterwards, the paved asphalt layer (phase 3, asphalt paving) was sampled. For this, drilling cores "BK" with different diameters were taken for examinations in phase 2, where the asphalt mix was paved.

The asphalt and bitumen of the sample material produced from phases 1 to 3 have been examined.

In addition to the conventional asphalt examinations, stiffness, fatigue behavior, low temperature behavior, deformation behavior and grip have been examined using the asphalt samples produced in the lab that were mixed in the lab and for large-scale production, as well as using the drilling cores.
The binder was subjected to performance-relevant examinations (BBR, KD, DSR, MSCR) and conventional examinations (determination of the softening point ring and ball, the needle penetration and elastic recovery).

How these determined indices behave in the phases of asphalt mix design (phase EP), asphalt mix production (phase MW) and after asphalt pavement (phase BK) and which new conclusions of contractual conditions can be derived from this can be taken from the final report of the research project [1]. In the scope of this article, the results of the bitumen examinations, determined with the dynamic shear rheometer, are explained in more detail.

2. EXPERIMENTAL

2.1 Material

The different mixes of the 21 examination routes can be assigned to six different binder types for surface and binder course asphalt with the classification criterion "binder used"; see table 1. As Table 1 reveals, the six varieties of binders were used different frequently.

Table 1: Binder types

Version	Binder	Mix	Number of mixes
1.	50/70	AC 16 B N; AC 11 D N	2
2.	10/40-65 A	SMA 16 B S	2
3.	10/40-65 A with addition binder 10/40-65 A RC	AC 16 B S; SMA 16 B S	4
4.	25/55-55 A	AC 16 B S; AC 22 B S; SMA 11 S; SMA 8 S AC 11 D S	17
5.	25/55-55 A with addition binder 25/55-55 A RC	AC 16 B S; AC 22 B S;	7
6.	40/100-65 A	SMA 8 LA	2

The binders have been examined with the dynamic shear rheometer in the delivery condition (phase AL) and the recovered condition from the mix (phase MW) and the drilling core (phase BK). Since the mixes of versions 3 and 5 had granulate added, the binder examinations in the DSR could only take place comparatively in the phases MW and BK using the resulting binder.

2.2 Test Methods

In the examinations in the dynamic shear rheometer, we differentiate between determination of the complex shear modulus and the phase angle (DSR test) and the determination of the deformation behavior of binders (MSCR test).

2.2.1 DSR Test

According to DIN EN 14770, the indices for the viscoelastic behavior of binders are the complex shear modulus and the phase angle, determined with the dynamic shear rheometer (DSR). To determine the characteristic values, the binder sample is installed between two parallel metal plates and exposed to a vibrating (oscillating) shear stress.
The oscillation of the upper plate causes deformation of the test material. Two types of measurements are differentiated:

- A defined shear tension (torque) is specified and the resulting deformation is measured (force-controlled test).
- A defined deformation is specified and the required shear tension (torque) is measured (path-controlled test).

In the scope of this research project, path-controlled tests were performed. The examinations took place purs. to AL DSR-Prüfung (T-Sweep) in the form of a temperature sweep at temperatures 30, 40, 50, 60, 70, 80 and 90 °C at a test frequency of 1.59 Hz. The defined target deformation chosen was 0.5 % referring to the sample height.

2.2.2 Multiple Stress Creep and Recovery Test

The dynamic shear rheometer can be used to replace the dynamic test (dynamic shear test) by a creep test purs. to the work instruction "AL MSCR test (DSR)". For the MSCR test, a consistent creep stress is applied to the binder test and the resulting deformation is measured over time. The test is performed at a consistent test temperature of 60 °C. The binder sample is subjected to a consistent stress (creep stress) for one second, followed by a force-free recovery phase of nine seconds. At three load stages (0.100, 1.600 and 3.200 kPa) 10 creep and recovery cycles are applied in direct sequence.
The measured values (deformation) permit determination of the respective average percentage recovery R for the creep stresses 0.100, 1.600 and 3.200 kPa and the average non-recoverable share J_{nr}.

3. RESULTS AND DISCUSSION

Figures 2 and 3 illustrate the averages and widths of the temperature sweep of the “complex shear modulus G*” and “phase angle φ“ determined at 60 °C.

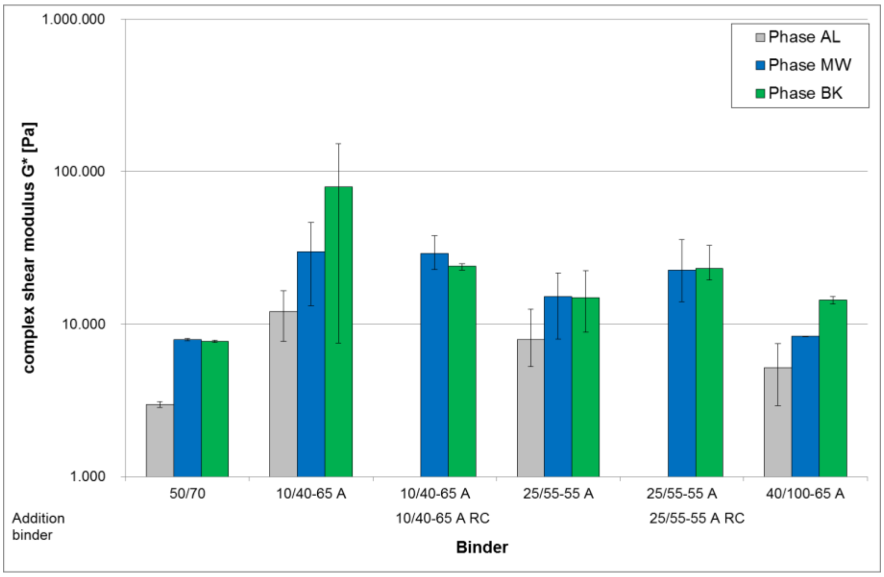

Figure 2: Graphical illustration of the averages and widths of the complex shear modulus of surface and binder course asphalt, grouped by binder type

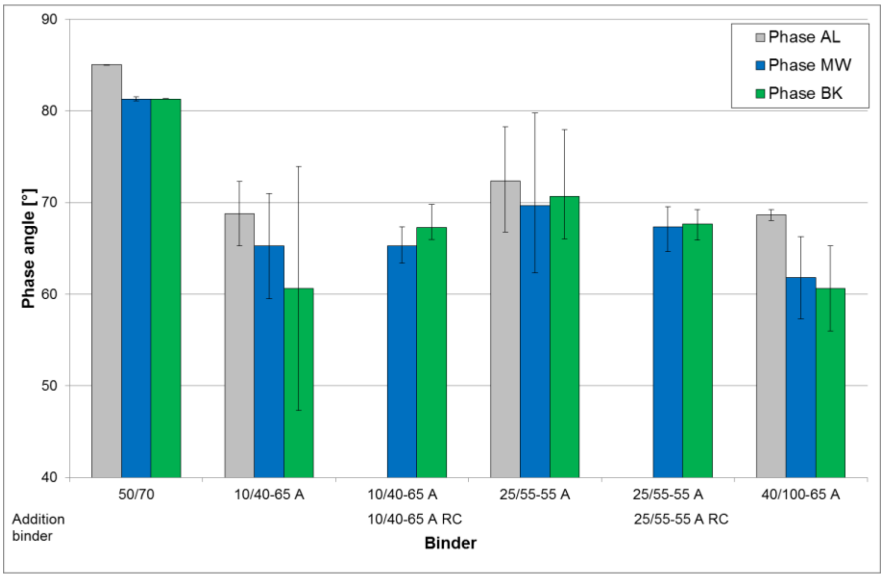

Figure 3: Graphical illustration of the averages and widths of the phase angle of binders for surface and binder course asphalt, grouped by binder type

As expected, the shear coefficients in phases MW and BK show higher values than in phase AL. A consistent trend between the size of the values of phases MW and BK for the binder types examined here could not be found. This suggests that the properties of the binder do not change considerably during installation of the asphalt.
The ranges of these values (complex shear modulus) are at a relatively low level, apart from the range of the values in binder 10/40-65 A phase BK. This suggests that the procedure is applicable.
In phases AL and MW, 50/70 binder has the lowest stiffness, followed by 40/100-65 A, 25/55-55 A and 10/40-65 A binder. The series of binder types in phases BK and MW corresponds to the previously described one under consideration of the binder types with added binder (10/40-65 A with 10/40-65 A RC and 25/55-55 A with 25/55-55 A RC).

The respective maximum value is determined for the phase angle in phase AL in all illustrated binder types. As already found by the property complex shear modulus, the phase angle also does not show any consistent trend between the values of phases MW and BK for the binder types examined here.
The largest values for phase angle are reached in all phases with the 50/70 binder, followed by the 25/55-55 A binder. The values for phase angles of the binder types 10/40-65 A and 40/100-65 A in phase AL are at a similar level. In phases MW and BK higher phase angles could be determined for binder 10/40-65 A than for binder 40/100-65 A.

The results of the multiple stress creep and recovery test for the binders listed in table 1 are shown in figures 4 and 5.

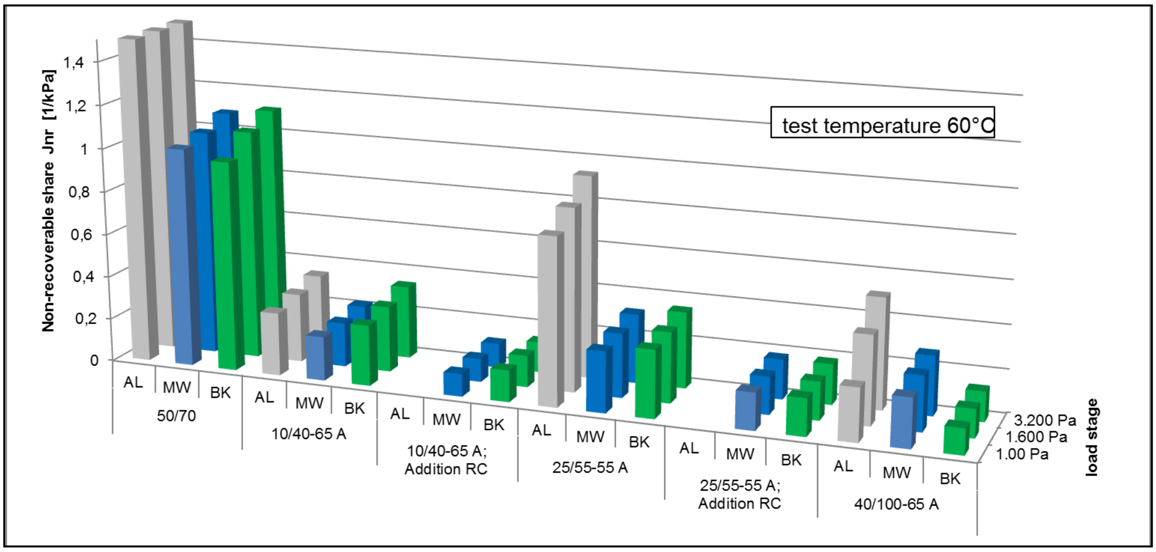

Figure 4: Graphical illustration of the averages of the "non-recoverable share" of binders for surface and binder course asphalt, grouped by binder type

The increased stiffness in phases MW and BK as compared to phase AL (see DSR test, property G*) causes the "non-recoverable share J_{nr}" to be smaller than in phase AL in all binder examined in phases MW and BK. A consistent trend of the binder for the "non-recoverable share" between the phases MW and BK cannot be found.
The 50/70 binder has the highest "non-recoverable share J_{nr}" as compared to the polymer-modified binder in all phases and load stages, followed by binder type 25/55-55 A. Binder 10/40-65 A on average has lower values across the three load stages for phases AL and MW than binder 40/100-65 A. This is different for phase BK, where the 40/100-65 A binder shows comparatively smaller averages for the "non-recoverable share".

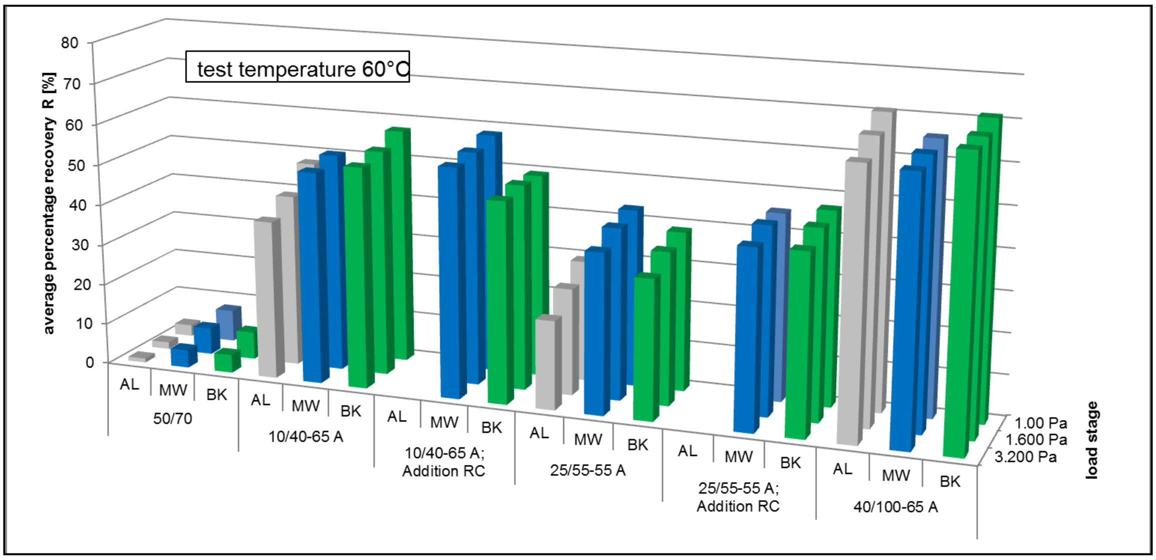

Figure 5: Graphical illustration of the averages of the "average percentage recovery" of binders for surface and binder course asphalt, grouped by binder type

The "average percentage recovery" is smaller in phase AL than in phases MW and BK in all examined binder, except for the binder 40/100-65A. A consistent ranking of phases MW and BK could not be established for all binder types.
Due to the lack of polymers in the 50/70 binder, the "average percentage recovery" is very low as compared to other binder. The 25/55-55 A binder shows much higher "average percentages recoveries" in all phases, followed by 10/40-65 A and 40/100-65 A binder.

A summary of the ranking for the binder characteristics (determined by DSR- and MSCR test) without statistical background is shown in table 2. With the binder characteristics "phase angle φ" (DSR-test) and "Non-recoverable share J_{nr}" (MSCR-test), the examined binder types can be ranked almost the same.

Table 2: Summary ranking of the different binder types

Binder characteristic	Phase	Ranking of the binder types (small values >>> large values)			
G*	AL	50/70	40/100-65 A	25/55-55 A	10/40-65 A
	MW	50/70	40/100-65 A	25/55-55 A	10/40-65 A
	BK	50/70	40/100-65 A	25/55-55 A	10/40-65 A
φ	AL	40/100-65 A	10/40-65 A	25/55-55 A	50/70
	MW	40/100-65 A	10/40-65 A	25/55-55 A	50/70
	BK	40/100-65 A	10/40-65 A	25/55-55 A	50/70
J_{nr}	AL	10/40-65 A	40/100-65 A	25/55-55 A	50/70
	MW	10/40-65 A	40/100-65 A	25/55-55 A	50/70
	BK	40/100-65 A	10/40-65 A	25/55-55 A	50/70
R	AL	50/70	25/55-55 A	10/40-65 A	40/100-65 A
	MW	50/70	25/55-55 A	10/40-65 A	40/100-65 A
	BK	50/70	25/55-55 A	10/40-65 A	40/100-65 A

The previous evaluation of the MSCRT purs. to the "work instructions for the determination of deformation behavior of bitumens and bituminous binders in dynamic shear rheometers (DSR) – examination of the MSCR test (Multiple Stress Creep and Recovery Test)“ [2] – is based only on the formation of ratios between the deformation at the start of the stress phase, the end of the stress phase and the end of the recovery phase. The firm “HNL Ingenieur- und Prüfgesellschaft mbH” is currently researching this subject to derive further indices from this test type. The first results on this have already been discussed in the research society for road and traffic management (Forschungsgesellschaft für Straßen- und Verkehrswesen) (AK 7.2.1, AA 7.2). They are explained below.

The flow behavior of binder can be described by **rheological indices** such as viscosity, elasticity and visco-elasticity. There are many test procedures to determine these indices. In contrast to dynamic procedures, such as oscillation measurement, the MSCR test can dissipate the characteristic values from statistical examination. However, this requires that the entire curve during the stress and recovery phases is analytically described per load cycle. The Burgers - Model (figure 6) is, e.g., suitable for this.

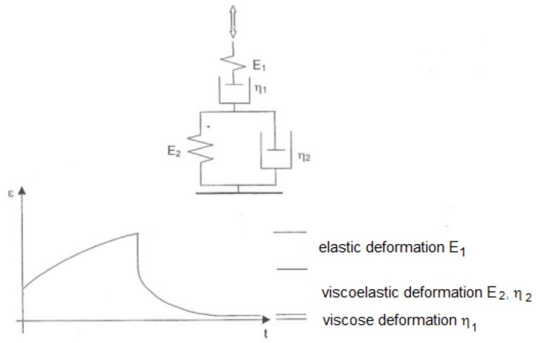

Figure 6: Burgers-Model

A strain-recovery developing comparable to the Burgers-Model is shown in the strain-recovery curves per load cycle as determined with the MSCR test. Figure 7 shows the strain-recovery curves across three load stages determined with four different binder types.

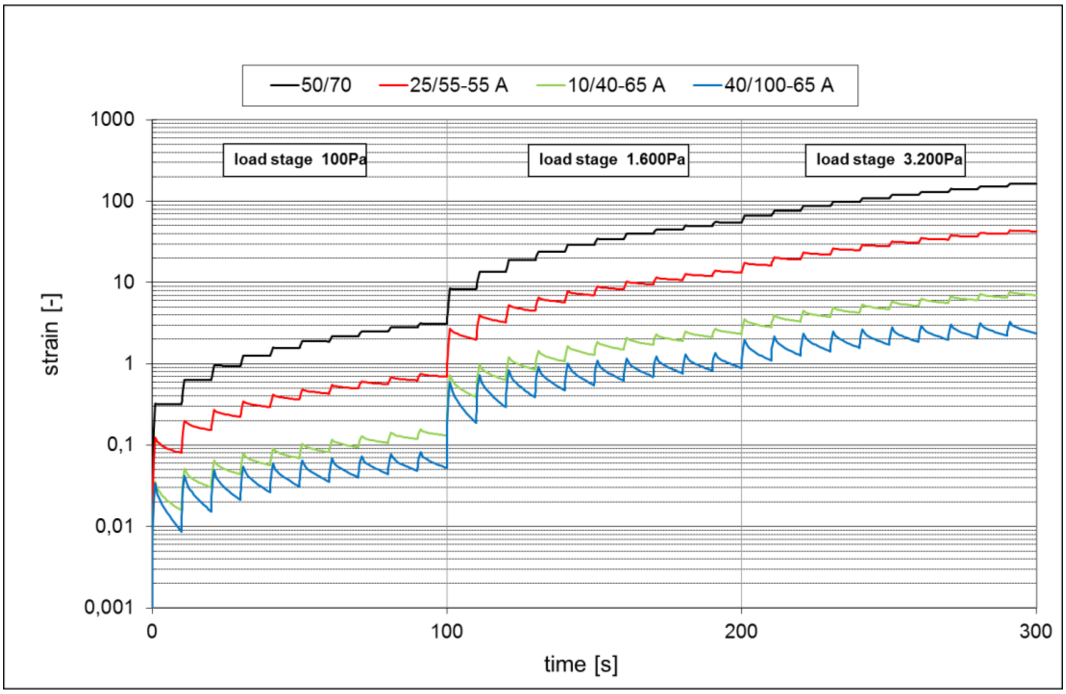

Figure 7: strain-recovery curves across three load stages for different binder types

To determine rheological characteristic values from these curves, the values measured (strain-recovery curve) per binder type have been verified by calculation for each binder type with the equation for the Burgers-Model and the method of the smallest error squares. First, all three load stages were considered in the calculation. As figure 8 shows, good correspondence between measured and calculated values could be achieved.

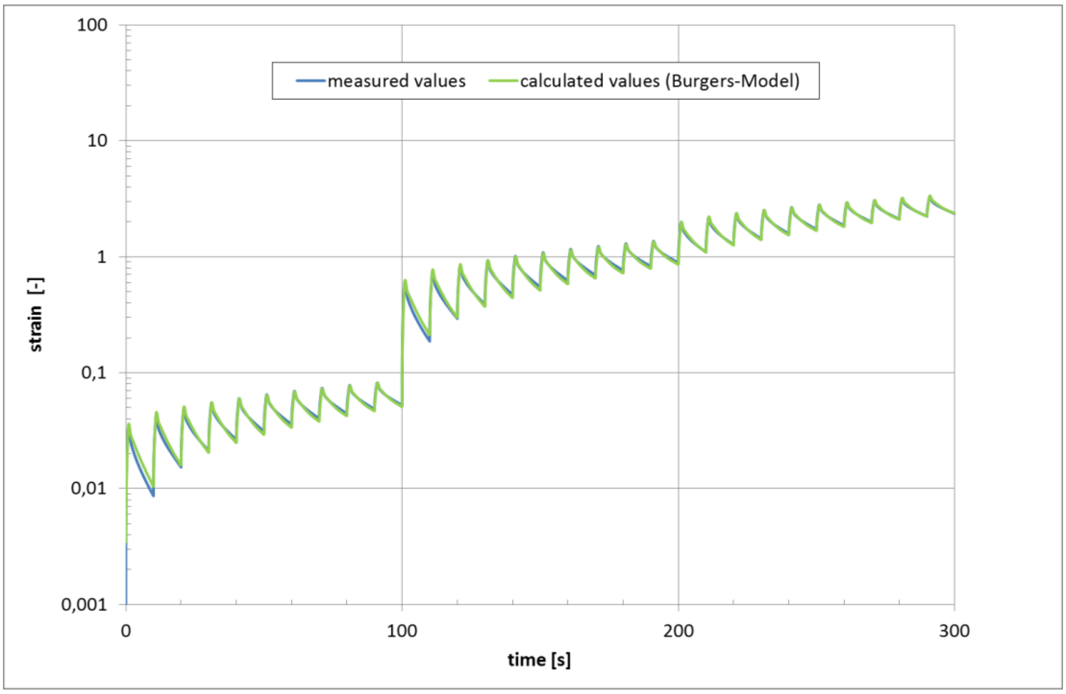

Figure 8: Measured and calculated (Burgers-Model) strain recovery curves

It was also reviewed whether the measured and calculated values also correspond well if the characteristic values E_1, E_2, λ_1 and λ_2 from the Burgers-Model are only determined with the measured values (MSCR test) from one load stage. A high degree of determination could be achieved for the approximation of the entire curve progress across the three different load stages.
By calculating the "real" rheological indices (E_1, E_2 and λ_1,λ_2) of strain recovery curves (see figure 6) it is possible to include prospective these indices in material models of asphalt.

4. CONCLUSION

The binder characteristic values determined in the scope of the research project [1] with the test methods MSCR and DSR (T-Sweep) in the various investigated phases from the asphalt mix design through asphalt production until asphalt pavement (AL, MW and BK) have been explained in more detail in this article.

Differences between phases AL and MW or BK could be determined for the binder types under consideration with the binder characteristics “non-recoverable share J_{nr}“ and “average percentage recovery R” for load stages 100, 1.600 and 3.200 Pa as well as “complex shear modulus G*” and “phase angle φ”.
A consistent trend for all binder types between phases MW and BK could not be found in any of the binder characteristic values.
It could be determined that the characteristic values “phase angle φ“ and "non-recoverable share J_{nr}" classify the examined binders almost the same when ranking the different binder types by phase and binder characteristic value.

Since the previous evaluation of the MSCR test took place based only on the formation of ratios between deformation at the start of the stress phase, at the end of the stress phase and at the end of the relaxation phases purs. to [2], the firm “HNL Ingenieur- und Prüfgesellschaft mbH” is currently researching the evaluation of further rheological characteristic values for this test type.
So the possibility was created to determine the rheological indices (E_1, E_2 and λ_1,λ_2) of the Burgers-Model from strain recovery curves by approximating the entire curve over the three different load stages.
These rheological indices could be included prospective in material models of asphalt.

REFERENCES

[1] Hase,M.; Roos,R.; Wörner T.; et al.: Schlussbericht zum FA Repräsentative Ermittlung der performance-relevanten Asphalteigenschaften als Grundlage neuer Vertragsbedingungen
BMVBS – Forschungsauftrag Nr. 07.0253/2011/ERB ; 2015, Germany

[2] FSVC, Arbeitsanleitung zur Bestimmung der Verformungsverhaltens von Bitumen und bitumenhaltigen Bindemitteln im Dynamischen Scherrheometer (DSR) – Durchführung der MSCR- Prüfung (Multiple Stress Creep and Recovery Test); FSVC Verlag Cologne, 2012