INFLUENCE OF DIFFERENCES IN QUALITY POLYMER MODIFIED BITUMINOUS BINDER SAME VARIETY ON THE MECHANICAL BEHAVIOUR OF ASPHALT, PART 1: DEFORMATION BEHAVIOUR UNDER HEAT

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ABSTRACT

The Hansa-Nord-Labor GmbH in Pinneberg was assigned on 19. August 2008 by the Federal Highway Research Institute (bast), representing the Federal Ministry of Transport, Building and Urban Development (BMVBS), to perform the research project FE 07.225/2008/BGB.
With this research project it was found that the different rheological material behavior of different binder same variety effects on the deformation behavior of asphalt under heat. With this knowledge, limiting values for binder in regard to rheological binder characteristics can be recommended or, respectively, can be incorporated as part of a functional construction contracts or as specifications.
To determine the different rheological material behavior of different binder same species on the deformation behavior of asphalt, three paving grades of bitumen (25/55-55A, 40/100-65A, 10/40-65A), each of them from four different producer, are used. Two surface course asphalts (AC 11 D S, SMA 11 S) and one binder course asphalt (AC 16 B S) were chosen.
Analyses were accomplished to determine conventional and rheological binder properties (EwP, RuK, Pen, el-R, KD, DSR, MSCE) in as-delivered condition and in accordance with DIN EN 12607-1 aged condition as well as characterization of the deformation behavior of asphalt (uniaxial compression test, three axial compression test, dynamic penetration test with a flat-ended dye).
It was found, that the determination of the rheological properties showed rather distinctly significant differences in the material behavior of binder same variety but from different producer than the conventionally tested binder properties.

Keywords: functional construction contracts, correlation asphalt - bitumen, rheology, deformation behaviour, request values

1. INTRODUCTION

The research project "optimization of the attempt-technical basic conditions for the execution and evaluation of performance-oriented bitumen investigations by dynamic shear rheometer"[1], [2] concluded that it is possible to differentiate between binders with regard to their rheologic material behaviour. These differences can be described by determination of the characteristics phase angle δ and complex shear modulus G* same grades of binder.
It should be examined within this research project FE 07.225/2008/BGB "Influence of differences in quality of polymer modified bituminous binder same variety on the mechanical behaviour of asphalt, Part 1: deformation behaviour under heat" to what extent the proved differences have an effect on the deformation behaviour of asphalt under heat. As a basis investigations are carried out with the objective to reveal correlations between rheologic characteristics of binder and asphalt properties. These asphalt properties describe the deformation behaviour of asphalt under heat. The aim is to find out whether there is a different rheological material behaviour of different binders same variety which has an effect on the deformation behaviour of asphalt under heat. If so there will be a substantial impact on the working life of the road construction.
Furthermore, based on this research requirement values for binders regarding rheological binder characteristics should be determined. These requirement values should be part of functional construction contracts or specifications. This can achieve an improvement of quality of asphalt with the consequences that the necessary repair of the road can be suspended and the service life of the road can be extended. This will have positive effects on the national economy and will be a relief for the budget.
A similar aim was pursued with the BiTVal project [3]. This project focused on finding suitable testing methods for the characterisation of relevant bitumen characteristics as well as on proving correlations of these characteristics to the asphalt characteristics. However, the BiTVal study just examined the correlation between the bitumen characteristics and the asphalt characteristic „rut depth".
In order to identify correlations with other asphalt characteristics, three further testing methods, which describe the deformation behaviour of asphalt under heat, are taken in the test program of this research project.

2. EXPERIMENTAL

2.1. Material

Three polymer binder products are chosen for the examination: 25/55-55A, 40/100-65A, 10/40-65A. Four different producers (Total Bitumen Deutschland GmbH, Nynas Belgium AB, Shell Deutschland Oil GmbH, BP Europa SE) have been selected. Each of them provided the mentioned three polymer binder for the examination to determine the different rheological material behaviour of different binder same variety on the deformation behaviour of asphalt. The SBS binders are crosslinked according to the specification of the producer. Only one producer use physical blends.The mineral aggregate mixture of the different mixture property variants consists of the grain size range greater than 2 mm existing of Granodiorit from Jelsa, Norway and of the grain size range less than 2 mm up to 0.063 mm existing of Diabas with a rate of a fortuitous filler of 5 – 8 M. - %. A limestone flour is selected as the filler aggregate.
Possible influences of different cavity contents of the asphalt on the deformation characteristics under heat are determined. For this purpose, two different compression levels (97 % - 98 % and 100 %) for each asphalt variant sample test specimen are examined.
In order to characterize the deformation behaviour of asphalt under heat, the following asphalts variants are produced:

Asphalt	binder	producer (binder)	compression level
AC 11 D S	25/55-55A	BP, Nynas, Shell, Total	100 % and 97-98 %
SMA 11 S	25/55-55A 40/100-65A	BP, Nynas, Shell, Total	100 % and 97-98 %
AC 16 B S	25/55-55A 10/40-65A	BP, Nynas, Shell, Total	100 % and 97-98 %

Table 1: asphalt variants

40 asphalt variants can be examined.
The different asphalt variants are produced in accordance with the new technical test provisions and composite in accordance with the TL asphalt StB 07. The different variants are produced with an asphalt labour coater.

2.2. Bitumen Investigation

In order to introduce the influence of the aging processes on the characteristics of the binders, the investigations on the different binder variants are carried out using binders in a as-delivered condition as well as in aged condition (in accordance with DIN EN 12607-1 (RTFOT procedure)). The following conventional and rheologic binder characteristics are determined:

- softening point ring and ball according to DIN EN 1427,
- needle penetration according to DIN EN 1426,
- elastic recovery by 25 °C according to DIN EN 13398,
- power ductility according to DIN EN 13589 and DIN EN 13703,

(25/55-55A and 40/100-65A by 5 °C, 10/40-65A by 10 °C),

- dynamic shear rheometer analytic according to DIN EN 14770, TL Bitumen-StB 07 (temperature sweep 30 – 90 °C, by a frequency of 1,59 Hz and a deformation of 0,5 %)
- multiple stress creep recovery (MSCR) Test according to AASHTO Designation: TP 70-07 by 50 °C,

The test is carried out at a constant temperature and a constant creep load of 1 s followed by a squeeze-free recovery by 9 s. The process is operated by load stages of 100 Pa and 3200 Pa. Ten cycles are carried out for each of the two load stages, so that 20 cycles are passed in total.

2.3. Asphalt Investigation

Uniaxial compression tests and dynamic penetration tests with a flat-ended dye are carried out using all of the 40 asphalt variants (four different bitumen producer, five above mentioned asphalt mixture and two compression levels).
The three axial compression tests are carried out using four different mixture variants. The SMA 11 S with the bitumen 25/55-55A of the four different bitumen producers and a compression level between 97 to 98 % are selected as asphalt for the three axial compression tests.
The test specimens are drilled out of plates in order to achieve a practical compression of the test specimen relevant for the uniaxial compression test, the dynamic penetration test and for the three axial compression test. These plates were produced using a segmented roller compactor according to the Braunschweiger compaction programme. Additionally test specimens for the uniaxial compression tests are produced using the Marshall Compactor.

2.3.1 Uniaxial Compression Test

The uniaxial compression test is carried out according to the German test provision TP A-StB Teil: „Einaxialer Druckschwellversuch – Bestimmung des Verformungsverhaltens von Walzasphalten bei Wärme“, edition 1999. This technical test provision describes a procedure, which emerges the deformation behaviour of asphalt at high temperature under dynamic stress.

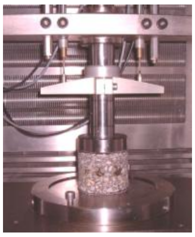

Figure 1: uniaxial compression test

As part of this procedure a haversine compressive load is put onto a cylindrical test specimen (∅ =100 mm, h=60mm) at isotherms test conditions. The course of this weight, which comprises sequences of load impulses (0.2 s) and load breaks (1.5 s), is in line with the technical test provision. The primary stress has been determined in accordance to the mixture with the objective to receive a turning point in the impulse creep curve as much as possible. Against this background the following primary stress was selected: AC 11: σ_o = 0,25 MPa, SMA: σ_o = 0,35 MPa, AC 16 : σ_o = 0,50 MPa. The inductive displacement transducer fixed at the traverse measure the deformation of the test specimen in load direction for every load cycles. The inspection temperature is 50 °C.

2.3.2 Dynamic Penetration Test

The dynamic penetration tests are carried out for all 40 asphalt variants in accordance to the „new “technical test provision TP A-25 A2 (Dynamischer Stempeleindringversuch an Walzasphalt) by 12.02.2009. This test has been chosen as it is European“ approach for the determination of the mechanical characteristics under heat.
The result of the dynamic penetration tests and the uniaxial compression tests also show which of them better reveals differences in quality of the asphalt material behaviour.

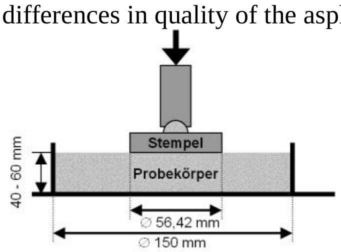

Figure 2: dynamic penetration test

A cylindrical specimen, which disposes of an even surface area and is fixed with a steel framework is exposed to a haversine compressive load. This load derives from a centrically aligned stamp with a diameter of 56,42 mm.

The course of the weight which comprises sequences of load impulses (0.2 s) and load breaks (1.5 s), is in line with the technical test provision. The primary stress σ_o amounts to a load surface of 2.500 mm² and a diameter of 56.42 mm, 0,8 MPa. The under-stress σ_u amounts to 0,02 MPa. The sample test specimen is built into a metal ring. The horizontal extension is totally prevented.

The test specimens were drilled out of asphalt slabs. These slaps are manufactured using a rolling sector compaction unit. The diameter of the sample test specimens amounts to 150 mm. In case of an asphalt surface layer mixture AC11DS and SMA11S the height amounts to 40 mm, in case of asphalt binder mixture AC16BS the height amounts to 60 mm.
The penetration depth of the stamp results from the repeated load, and is recorded for each load cycles. The inspection temperature is 50 °C.

2.3.3 Three Axial Compression Test

The DIN EN 12697-25 (2005) procedure describes the determination of stability of asphalt compared to permanent deformation by compression tests with handicapped lateral extensions. This procedure classifies different types of asphalt according to the deformation resistance. Furthermore, it is applied for initial inspection.

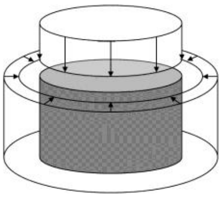

Figure 3: three axial compression test

Though, a cylindrical asphalt specimen is exposed to a three axial tensil state. This state arises from an axial cyclic load and a static or dynamic radial load. The DIN EN determines that the cyclic load is preferable over static load in order to hamper the lateral extensions in stead as dynamic radical reactions arise from dynamic axial loads. A pressure cell has been developed at the institute of high way engineering of the TU Braunschweig particularly for this type of test. This cell enables that the sample test specimen can be loaded dynamic axial as well as dynamic radical. The cell also allows for a dephased radical load due to the viscoelastic behaviour of asphalt.

The axial tension σ_{ax} amounts to 0,8 MPa under the assumption of 11,5 tons axle and a road-contact area with a diameter from 300 mm. The procedure to define the radical tension was developed in the research project „Optimierung des Triaxialversuchs zur Bewertung des Verformungswiderstandes von Asphalt"[4]. This procedure makes it possible to determine a material-dependent radical tension independent of the kind of asphalt and sort.
The three axial compression tests are carried out without load break and with a frequency by 10 Hz. This frequency complies with a vehicle with a speed of 60 km/h. The phase shift from the sinusoidal axial to the radical load is specified on 10 ms. This reflects the close-to-reality speech of the viscoelastic material behaviour from asphalt. The inspection temperature is 50 °C.
The permanent axial strains as well as the rate of strain at the end of the test and/or in the turning point of the impulse creep curve are evaluated as it was carried in the context of the other tests.

3. RESULTS AND DISCUSSION

In total, 90 binder properties both conventional and rheological are evaluated statistically (30 binder properties for each product). In 90% of the cases the average value of bitumen of one producer significantly differs from the average value of the products of the other producers (for example figure 4). In 22% of the cases the average value of the four bitumen of the same variety from different producer significantly differ from each other. In consequence, there are four homogeneous groups of which each disposes of only one bitumen of one producer (for example figure 5).

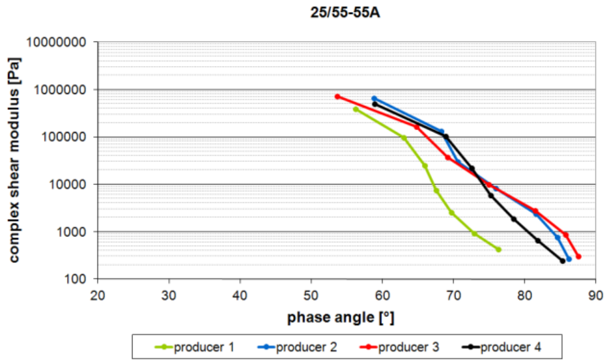

Figure 4: black diagram, 25/55-55A

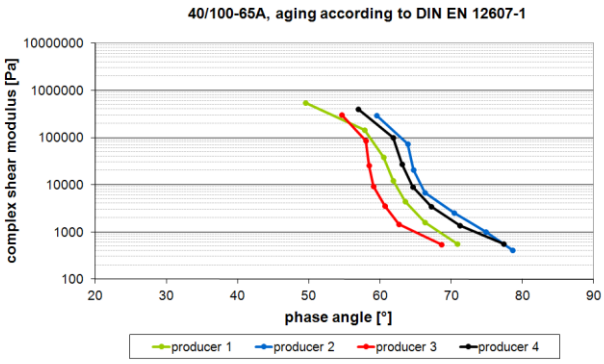

Figure 5: black diagram, 40/100-65A, aged

Furthermore, it can be stated that the rheological characteristics are more suitable than the conventional binder characteristics to show differences of the material behaviour in case bitumen of the same variety but different producer has been used.
The mathematical-statistic procedures show that the rheological binder characteristic phase angles - being determined at 50 °C after RTFOT aging - is different for all four products of the different bitumen producers for all three different binder grades. In consequences, there are four homogeneous groups of which each disposes of only one product of one producer.
Only two of three examined binder grades (25/55-55A and 40/100-65A) show a similar features - as describes in the previous sentence - for the rheological binder characteristics "percent recovery in as-delivered condition with 1600 Pa and 3200 Pa (MSCR test)" (see table 2) .

characteristic [unit]	25/55-55A				40/100-65A				10/40-65A			
	p 1	p 2	p 3	p 4	p 1	p 2	p 3	p 4	p 1	p 2	p 3	p 4
percent recovery 100 Pa [%]	58,3	17,6	22,7	36,5	74,6	63,9	87,8	69,4	76,9	53,6	55,7	56,8
percent recovery 1.600 Pa [%]	54,5	16,4	20,3	36,7	71,6	59,6	89,9	62,5	65,8	48,1	48,6	57,5
percent recovery 3.200 Pa [%]	53,3	14,7	18,3	34,0	74,1	56,3	90,7	65,0	64,5	47,7	48,4	58,0

Table 2: Results - MSCR-test

The strain and the rate of strain in the turning point and/or at the end of the test have been determined by applying the three different above-mentioned testing methods. They are used to describe the deformation behaviour of asphalt. The strain as well as the rates of the strain determined by the dynamic penetration test and the three axial compression tests do not reveal differences between the products of different bitumen producer in contrary to the results of uniaxial compression tests, which clearly show the different behaviour of the products. The results of the uniaxial compression tests are shown in figure 6.

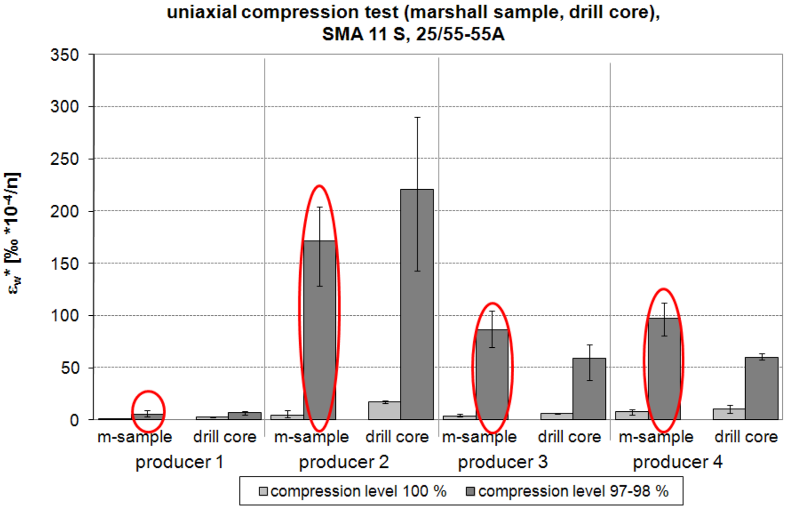

Figure 6: results - uniaxial compression test

The differences in rheological behavior of bitumen same variety are more precisely visible at a compression level about 97 to 98% than for compression levels about 100%.

Correlations between the binder characteristics and the asphalt characteristic values are drawn up by using simple regression analyses in order to determine requirement values for binder regarding rheological characteristic values.
The analysis results in the outcome that the "rates of strain" determined by using the uniaxial compression tests correlates best with the binder characteristics "average, percent recoveries with 1600 and 3200 Pa" determined by using the MSCR test (figure 7). A further good correlation exists between the above mentioned asphalt characteristic (rate of strain) and the phase angle at 50 °C after RTFOT aging (figure 7).

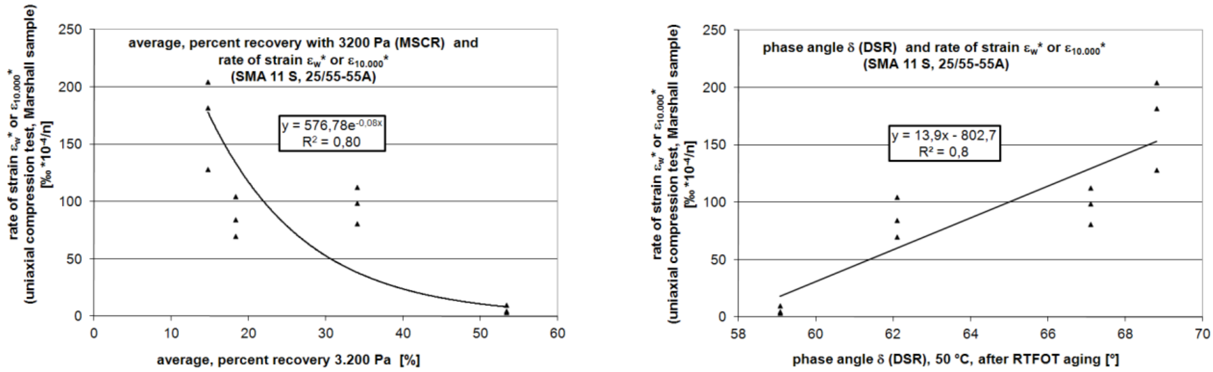

Figure 7: correlation between binder and asphalt characteristics

The results of the regression analyses is linked with evaluation criteria for reaching asphalt with good deformation behaviour under heat, which were extracted from the literature.
Evaluation background and/or evaluation standards on the rate of strain determined in uniaxial compression test can be inferred from literature. This information on the rate of strain is limited to the SMA with a maximum particle size of 11 mm.
In the context of this research project, requirement values for the bitumen characteristics phase angle at 50 °C after RTFOT aging (DSR) and for the characteristic average, proportional recovery with 50 °C and 3200 Pa (MSCR) are determined in order to achieve a deformation-steady asphalt. As there is no data on this in literature available, the research project only focused on the above-mentioned mixture (SMA 11 S) with bitumen 25/55-55A and 40/100-65A
Example:
According to the literature [6] the value of the rate of strain ε_w* or $\varepsilon_{10.000}$ should be bigger than 50 [‰ *10^{-4}/n] for traffic stress (site categoriey IV and higher) and the above mentioned asphalt.
It is possible to determine requirement values for a binder characteristic on the basis of the results of the regression analysis (figure 8).

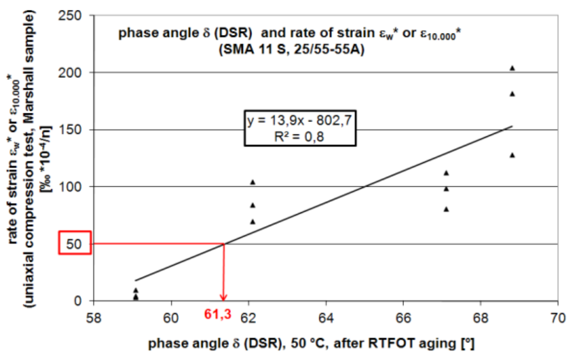

Figure 8: Proceeding to get requirement values

In table 3 the requirement values are shown as a function of the traffic stress. The requirement values of the above mentioned bitumen characteristics apply to SMA 11 S with a degree of compression between approx. 97 and 98%. The data of this table is based on the results of the examinations of sample test specimens produced with the Marshall compactor.

mix type / **compaction degree** / bitumen grade	SMA 11 S / **97 - 98 %** / 25/55-55A		SMA 11 S / **97 - 98 %** / 40/100-65A	
traffic stress	**requirement value average, proportional recovery with 50 °C and 3200 Pa (MSCR-test) [%]**	**requirement value phase angle after RTFOT aging, 50 °C (DSR-analytic) [°]**	**requirement value average, proportional recovery with 50 °C and 3200 Pa (MSCR-test) [%]**	**requirement value phase angle after RTFOT aging, 50 °C (DSR-analytic) [°]**
site category IV and higher	at least 30,6	**at least 61,3**	at least 53,8	at least 64,6
site category III-II	at least 37,0	at least 59,9	at least 60,2	at least 62,1
site category SV and I with normal demand	at least 41,4	at least 59,3	at least 64,7	at least 61,0
site category SV and I with especial demand				
up to 20 Mio. equivalent 10-t axle load transitions within 10 years	at least 47,4	at least 58,7	at least 70,7	at least 60,0
up to 30 Mio. equivalent 10-t axle load transitions within 10 years	at least 52,0	at least 58,4	at least 75,3	at least 59,5
up to 50 Mio. equivalent 10-t axle load transitions within 20 years	at least 57,1	at least 58,2	at least 80,3	at least 59,1
up to 70 Mio. equivalent 10-t axle load transitions within 20 years	at least 59,4	at least 58,1	at least 82,6	at least 59,0

Table 3: requirement values set up for mastic asphalt SMA 11 S with a degree of compression (97 – 98 %) and binder grades 25/55-55A and 40/100-65A.

4. CONCLUSION

Based on the present findings there should be more focus on the determination of rheological bitumen characteristics than on conventional bitumen characteristics in the future. In praxis it is of particular interest in this context that rheological bitumen characteristics in fact affect the deformation behaviour of asphalt under heat. These characteristics are influenced by the elasticity and by the recovery, however less by the stiffness of the bitumen (i.e. complex shear modulus G*).

The proposed requirement values for bitumen characteristics of SMA 11 S with degrees of compression between approx. 97 to 98% (table 3) can already be very helpful for the asphalt technologist in the creation process of the initial testing. According to the expected traffic stress a particular sort of bitumen can be chosen – it is especially relevant for the moment if the demanded degree of compression according to ZTV Asphalt-StB 07 is achieved – to get asphalt with a high resistance against deformation.

According to the technical literature the "in situ adjusting rutting development" reacts faster in case the rate of strain, which has been determined in the uniaxial compression test, is increasing.
It can be concluded that smaller rates of strain of the SMA, such as a higher average percent recoveries at 50 °C and 3200 Pa of the used bitumen in as-delivered condition and lower phase angles at 50 °C after RTFOT aging of the assigned bitumen, lead to less rutting within a certain period. The mentioned measured variables have an affect to the substantial quality criterion of the pavement: as small rutting as possible.
In order to maintain the quality of asphalt in systematic way - meaning that the service life of the road can be extended and the necessary repair of the road can be suspended. This will be relief for the national economy - it is recommended to select one of the following two approaches in practice:

1). If a minimum degree of compression of the SMA reaches at least a level of 97%, the requirement values of bitumen should be stated according the above mentioned rheological bitumen characteristics in function building contracts or specifications in the case.
By this, the effects of the significant differences in the rheological material behaviour of bitumen same variety can especially influence the deformation behaviour of the SMA under heat at a degrees of compression between approx. 97 to 98%.

2). A definition of a minimum degree of compression over 98 % (i.e. 99-100%) should be stated as a requirement value in function building contracts or specifications. By this it can be guaranteed that the existing significant differences in the rheological material behaviour of bitumen same variety do not or just slightly affects the deformation behaviour of mastic asphalt under heat. This does not apply in case of very large traffic stress (higher site category SV and I with normal demands).

In addition, AC 11 and AC 16 regression equations were determined in a similar way as it was for the SMA. However, an evaluation background is currently not available for these mixtures. In consequence, requirement values for rheological bitumen characteristics cannot be derived. Therefore, it is key to work on the creation of evaluation background for other asphalt grads. This evaluation background together with the regression equations for AC 11 and AC 16 as stated in this research project, would enable to determine the requirement values for rheological bitumen characteristics.

On the basis of the evaluation background of uniaxial compression tests at SMA requirement values for rheological bitumen characteristics could be determined within this research project.
However, this did not work for the dynamic penetration test according to the draft of the technical test provision TP A-25 A2 „Dynamischer Eindringversuch an Walzasphalt", February 2009 and for the three axial compression test following DIN EN 12697-25 part B. Still, the question remains unanswered whether there are significant differences in the rheological material behaviour of bitumen of the same variety but different producer under changing test conditions and/or changes in the evaluation of the results gained in two testing methods specified above and whether these difference have an effect on the results of the mentioned deformation tests. Therefore further research activities are mandatory according the opinion of the research editor.

Finally, it should be pointed out that the service life of an asphalt pavement depends on the deformation behaviour under heat as well as on stiffness, fatigue behaviour and low-temperature performance. At present, the Hansa-Nord-Labor examines whether the differences in quality of polymer modified bituminous binder of the same variety exist and whether they have an influence on these three characteristics mentioned last.

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