# Evaluation of rheological parameters regarding the resistance to permanent deformation

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Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.032

## ABSTRACT

*The systematic influencing of the performance related properties of binders grows in importance, taking into consideration the necessity to ensure the durability of increasingly stressed road pavements. With the growing binder variety, i. e. by modifications with various polymers, not only the complexity of the specific temperature dependent characteristics of these binders increases but also the testing methods referring to these characteristics have to be adapted.*

*Binder tests in the dynamic shear rheometer (DSR) provide the characteristic parameters complex shear modulus and phase angle. Based on these parameters the contribution of the binder to the resistance against deformation of the asphalt within the upper range of the functional temperature can be judged. Whereas the complex shear modulus describes the stiffness of the binder, the phase angle provides a statement about the shares of elastic and viscous behaviour. However, it is still not known which of both parameters is suitable to forecast the effect of the binder in the asphalt.*

*For this purpose a research program was developed in which four different types of binder, i. e. a polymer modified bitumen, a paving grade bitumen, a bitumen of modified viscosity and an oxidized bitumen, were processed in an asphalt concrete and afterwards subject to the Cyclic compression test according to EN 12697-25. Before the used binders were designed in such a way, that on the one hand they had the same complex shear modulus and on the other hand the same phase angle at the testing temperature of 50 °C during the Cyclic compression test. The properties of the polymer modified bitumen were used as reference.*

*In this paper the characteristics of the binders and the results of the asphalt tests are presented and at the same time being discussed.*

**Keywords:** Complex Modulus, Mechanical Properties, Modified Binders, Performance testing

## 1. INTRODUCTION

The binder test by means of the dynamic shear rheometer (DSR) with which the parameters of the complex shear modulus G* and the phase angle δ are determined comes from the American Strategic Highway Research Program (SHRP). These parameters are used to classify the binder with regard to suitability for a defined service temperature range of the asphalt. The contribution of the binder to the deformation behaviour of the asphalt in the higher service temperature range is expressed by the quotient G*/sinδ. The experiences with the binder classification led to the understanding, that the chosen method to predict the resistance against rutting is insufficient [1, 2, 3].
On this occasion a special investigation program was realized which was to provide information which of the binder properties determined with the DSR show an influence on permanent deformations in the asphalt.

## 2. TEST METHOD

Four different kinds of binders were prepared in order to guarantee that they show the same complex shear modulus at a chosen test temperature of 50 °C. Additionally variants were mixed with these binders which have the same phase angle at the defined temperature.. The characteristics of a polymer modified bitumen (PmB) of the grade 25/55-55 were used as relevant benchmark. Therefore the target value of the complex modulus of the variants 2.1, 3.1 and 4.1 was G* = 21.5 kPa, which is the complex modulus of the PmB. The target value of the phase angle of the variants 2.2 and 3.2 was δ = 71,7 ° (Table 1). For reaching the same qualities, the binders - with the exception of the PmB - were blended by different grades of paving grade bitumen respectively of oxidized bitumen. The preparation of a wax modified bitumen with a comparable phase angle was not successful. In particular the following binder grades were tested:

- Polymer modified bitumen with 3 % styrene-butadiene polymer
- Paving grade bitumen
- Oxidized bitumen
- Paving grade bitumen with 3 % Fischer-Tropsch wax

Besides the rheological characteristics in the DSR also the conventional binder characteristics were determined. The tests included:

- Complex Shear modulus
- Phase angle
- Softening Point Ring and Ball
- Needle Penetration

Afterwards asphalt was produced with the binder variants and subsequently it was compacted to specimen. The mineral aggregates required for the production of the mixtures were released from oversize and undersize by washing and sieving. In order to stress the influence of the binder on the deformation behavior of the asphalt an asphalt concrete AC 11 was chosen. The asphalt specimen were exposed to the following dynamic tests:

- Uniaxial Cyclic Compression Test
- Dynamic Penetration test

The results of the binder and asphalt tests were evaluated and statistically analyzed on possible correlations.

## 3. TEST RESULTS

### 3.1 Binder Tests

The needle penetration was determined according to EN 1426, the softening point ring and ball according to EN 1427. The determination of the complex shear modulus and the phase angle in the DSR was realized according to EN 14770. The tests were carried out at a frequency of 1,59 Hz.

**Table 1: Results of the binder tests**

| Binder grade | Variant | Needle Penetration | Softening Point Ring and Ball | Complex Shear Modulus at 50 °C | Phase angle at 50 °C |
|---|---|---|---|---|---|
| | | [dmm] | [°C] | [kPa] | [°] |
| Polymer modified Bitumen | 1.0 | 47 | 58,2 | 21,5 | 71,7 |
| Paving grade bitumen | 2.1 | 43 | 54,0 | 21,7 | 78,2 |
| | 2.2 | 23 | 62,0 | 76,6 | 72,6 |
| Oxidized bitumen | 3.1 | 60 | 76,4 | 23,3 | 49,1 |
| | 3.2 | 108 | 47,8 | 4,6 | 73,1 |
| Paving grade bitumen with Wax | 4.1 | 79 | 84,0 | 23,0 | 64,0 |

To be able to evaluate the results of the dynamic tests on the asphalt it was necessary to determine the relevant binder characteristics in the DSR at the same test temperature. Accordingly the tests in the DSR were carried out at 50 °C. The test results of the different binders are given in table 1.

### 3.1 Asphalt Tests

In order to determine the deformation properties of the asphalts produced with the different binder types uniaxial cyclic compression test according to EN 12697-25 B as well as dynamic penetration tests according to EN 12697-25 A2 were performed.
The specimen from the asphalt mixture AC 11 for the test by means of the uniaxial cyclic compression test were produced according to EN 12697-30 by impact compaction (Marshall). The void content of the compacted specimens and test results of the uniaxial cyclic compression tests are given in table 2.

**Table 2: Results of uniaxial cyclic compression tests**

| AC 11 with Binder grade | Variant | Void content | Number of loading cycles | | Strain | | Deformation | | Strain rate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | [vol.-%] | [-] | | [‰] | | [mm] | | [‰·$10^{-4}$/n] | |
| Polymermodified Bitumen | 1.0 | 1,8 | 10000 | 10000 | 33,38 | 35,33 | 2,00 | 2,12 | 10,69 | 9,94 |
| | | | 10000 | | 38,10 | | 2,29 | | 10,86 | |
| | | | 10000 | | 34,52 | | 2,07 | | 9,94 | |
| Paving Grade Bitumen | 2.1 | 1,5 | 10000 | 10000 | 32,26 | 33,37 | 1,95 | 2,01 | 11,81 | 12,81 |
| | | | 10000 | | 32,79 | | 1,98 | | 12,17 | |
| | | | 10000 | | 35,05 | | 2,12 | | 14,44 | |
| | 2.2 | 1,7 | 10000 | 10000 | 16,03 | 17,06 | 0,96 | 1,03 | 1,92 | 2,23 |
| | | | 10000 | | 17,62 | | 1,06 | | 2,38 | |
| | | | 10000 | | 17,54 | | 1,06 | | 2,39 | |
| Oxidized Bitumen | 3.1 | 2,4 | 10000 | 10000 | 17,86 | 18,91 | 1,07 | 1,14 | 3,05 | 2,87 |
| | | | 10000 | | 19,32 | | 1,16 | | 3,33 | |
| | | | 10000 | | 19,56 | | 1,17 | | 2,22 | |
| | 3.2 | 1,5 | 2116 | 1926 | 37,02 | 37,80 | 2,22 | 2,27 | 39,77 | 47,77 |
| | | | 2026 | | 39,26 | | 2,36 | | 45,96 | |
| | | | 1636 | | 37,13 | | 2,23 | | 57,59 | |
| Paving Grade Bitumen with Wax | 4.1 | 1,6 | 10000 | 9072 | 44,89 | 40,19 | 2,71 | 2,43 | 12,69 | 16,85 |
| | | | 7216 | | 28,75 | | 1,74 | | 21,63 | |
| | | | 10000 | | 46,92 | | 2,83 | | 16,23 | |

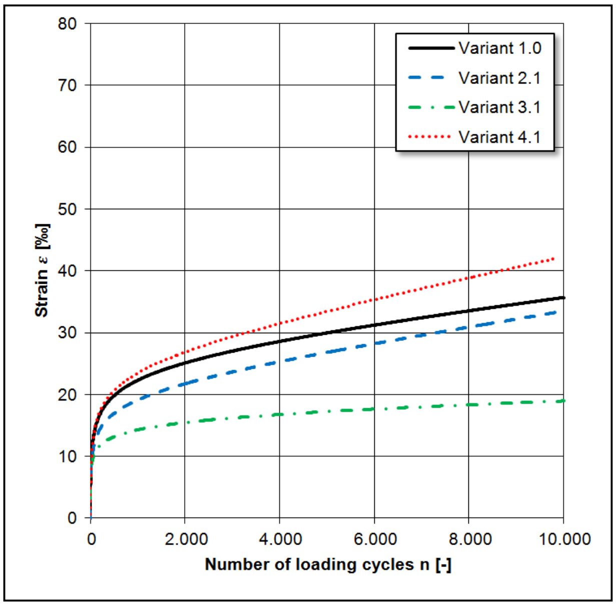


**Figure 1: Results of uniaxial cyclic compression test at AC 11 with binders of the same complex shear modulus**

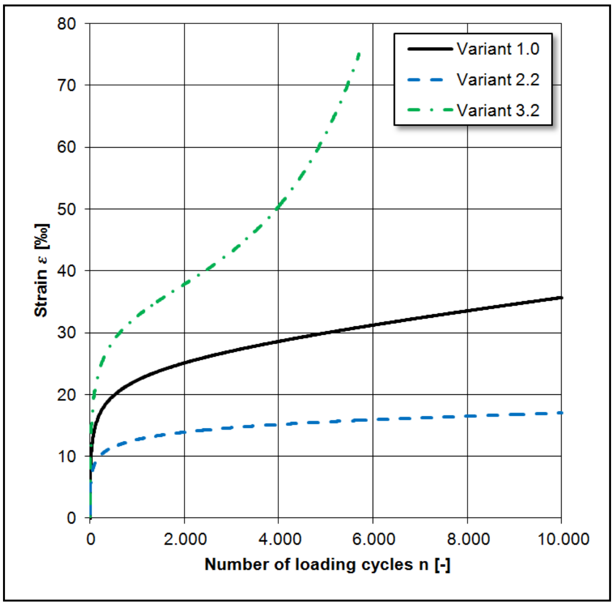


**Figure 2: Results of uniaxial cyclic compression test at AC 11 with binders of the same phase angle**

For the dynamic load of the asphalts in the uniaxial cyclic compression test the following test methods were chosen:

- Test temperature: 50 °C
- Mode of Loading: sinusoidal loading (0,2 s) with load stop (1,5 s) after each cycle
- Lower stress level: 0,025 MPa
- Upper stress level: 0,35 MPa

The tests were stopped after 10000 loading cycles, unless a premature failure of the specimen occured.
Figure 1 shows the strain as a function of the number of loading cycles of the asphalt specimens which have a comparable complex modulus of the binder. The results of the mixes containing binders with the same level of phase angle are shown in figure 2.

For the dynamic penetration test cylindric specimen with a diameter of 200 mm and a specimen height of 40 mm were used. The specimen were drilled out of asphalt slabs which were produced by means of roller compaction device according to EN 12697-33. As test conditions for the stress in the dynamic penetration test the following parameters were fixed:

- Test temperature: 50 °C
- Loading mode: sinusoidal loading at a frequency of 10 Hz
- Lower stress level: 0,02 MPa
- Upper stress level: 0,8 MPa

The number of loading cycles, which could be borne by all types without recognizable failure amounted to 100000. The void content of the compacted specimens and test results of the dynamic penetration tests are given in table 3.

**Table 3: Results of dynamic penetration tests**

| AC 11 with binder grade | Variant | Void content | Number of loading cycles | | Strain | | Deformation | | Strain rate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | [vol.-%] | [-] | | [‰] | | [mm] | | [‰·10⁻⁴/n] | |
| Polymermodified Bitumen | 1.0 | 1,6 | 100000<br>100000 | 100000 | 77,95<br>82,36 | 80,15 | 3,19<br>3,35 | 3,27 | 4,29<br>4,45 | 4,37 |
| Paving Grade Bitumen | 2.1 | 1,6 | 100000<br>100000 | 100000 | 71,53<br>63,78 | 67,66 | 2,90<br>2,58 | 2,74 | 3,89<br>3,53 | 3,71 |
| | 2.2 | 1,6 | 100000<br>100000 | 100000 | 56,63<br>67,69 | 62,16 | 2,29<br>2,74 | 2,52 | 2,84<br>3,20 | 3,02 |
| Oxidized Bitumen | 3.1 | 2,0 | 100000<br>100000 | 100000 | 66,23<br>73,08 | 69,66 | 2,73<br>3,01 | 2,87 | 3,51<br>3,40 | 3,45 |
| | 3.2 | 1,5 | 100000<br>100000 | 100000 | 96,64<br>91,67 | 94,16 | 3,88<br>3,71 | 3,80 | 6,02<br>5,92 | 5,97 |
| Paving Grade Bitumen with Wax | 4.1 | 1,5 | 100000<br>100000 | 100000 | 93,74<br>65,15 | 79,44 | 3,77<br>2,62 | 3,20 | 3,95<br>4,35 | 4,15 |

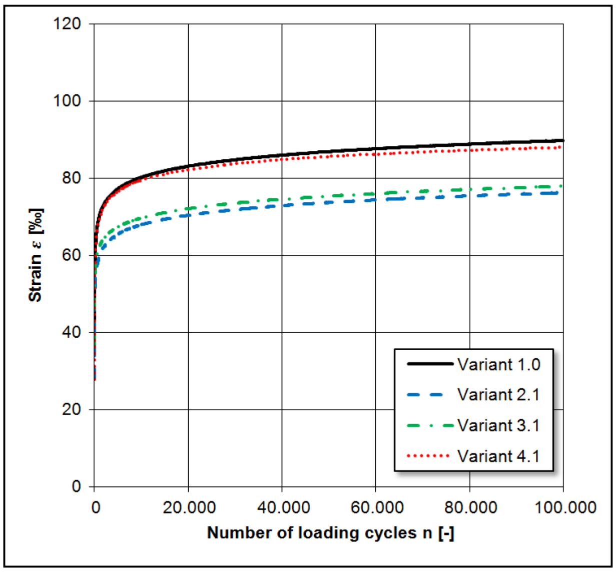


**Figure 3: Results of dynamic penetration test at AC 11 with binders of the same complex shear modulus**

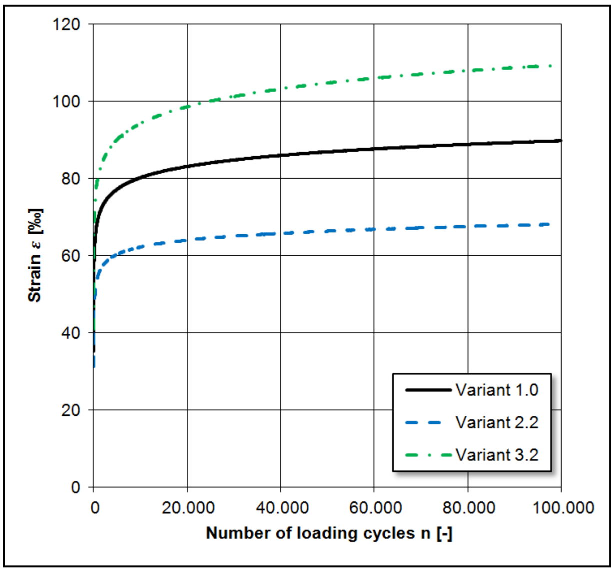


**Figure 4: Results of dynamic penetration test at AC 11 with binders of the same phase angle**

In figure 3 the strain in correlation to the number of loading cycles of the variants with the same complex modulus are represented. The results of the dynamic penetration test of the samples with binders, which have a similar phase angle, are shown in figure 4.

## 4. ANALYSIS

The targeted preparation of the binders regarding a property should be used to test possible influences of the binder characteristics on the deformation behaviour of the asphalt. If one of the specific binder values from the DSR is relevant for the asphalt property, it should be possible to verify a similar deformation behavior in the asphalt provided that the complex shear modulus respectively phase angle are of the same size.
In order to evaluate the results of the study, the tests results are exposed to a one-way analysis of variance with modified LSD-test (Least-Significant Difference Test). With this statistical analysis procedure the equality of the mean values of several sample groups is reviewed. The null hypothesis „all mean values are equal“ is with an exceeding probability of $\alpha$ = 0,05 discarded or confirmed.
Furthermore the modified LSD-test states, which mean values can be summarized to homogenous groups, that means they come from the same population. To this end the mean values are classified according to their size in descending order and it is checked, whether adjacent mean values show a bigger difference than the least significant difference. The findings of the statistical analysis for the uniaxial cyclic compression tests are given in table 4. Table 5 contains the results of the calculations for the dynamic penetration tests.

**Table 4: Results of the one-way analysis of variance with modified LSD-Test**

| Uniaxial cyclic compression test | Variants | Strain | Deformation | Strain rate |
|---|---|---|---|---|
| G* = const. | 1.0<br>2.1<br>3.1<br>4.1 | 4.1 = 1.0 = 2.1 > 3.1 | 4.1 = 1.0 = 2.1 > 3.1 | 4.1 = 2.1 = 1.0 > 3.1 |
| δ = const. | 1.0<br>2.2<br>3.2 | 3.2 = 1.0 > 2.1 | 3.2 = 1.0 > 2.1 | 3.2 > 1.0 = 2.1 |

**Table 5: Results of the one-way analysis of variance with modified LSD-Test**

| Dynamic penetration test | Variants | Strain | Deformation | Strain rate |
|---|---|---|---|---|
| G* = const. | 1.0<br>2.1<br>3.1<br>4.1 | 1.0 = 2.1 = 3.1 =4.1 | 1.0 = 2.1 = 3.1 =4.1 | 1.0 = 2.1 = 3.1 =4.1 |
| δ = const. | 1.0<br>2.2<br>3.2 | 3.2 = 1.0 > 2.1 | 3.2 = 1.0 > 2.1 | 3.2 > 1.0 > 2.1 |

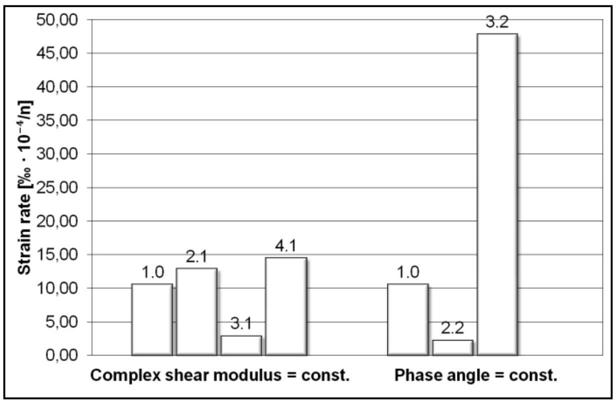


**Figure 5: By means of uniaxial cyclic compression test at AC 11 determined strain rates of the different binder types**

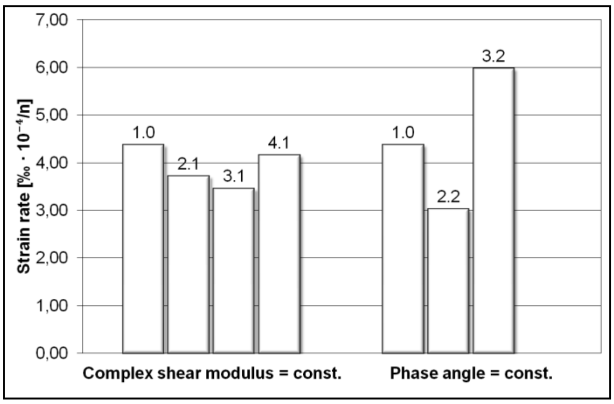


**Figure 6: By means of dynamic penetration test at AC 11 determined strain rates of the different binder types**

As it is shown in figure 5, the variants with the same complex modulus also show similar values of the strain rate determined by uniaxial compression test. The samples with binders with comparable Phase angle behave differently. The results of the dynamic penetration test support no differentiation (Figure 6).

## 5. CONCLUSIONS

Contrary to the dynamic penetration test with the uniaxial cyclic compression test a direct dependency of the binder properties gained by means of DSR could not be verified. Possibly this finding results from the missing radial stress in the asphalt specimen during the loading.

Whereas the statistical analysis of the results from the dynamic penetration test reveals that binders with the same value of the complex shear modulus also effect the same deformation properties in the asphalt. With the same complex shear modulus of the different binder grades the mean values of strain, deformation and deformation rate are equal. With the binders of equal phase angle this correspondence could not be observed. According to these findings it must be assumed that the complex shear modulus of a binder considerably influences the deformation resistance of asphalt. Whereas the phase angle of the binder seems to be of only minor importance for the deformation properties.

## ACKNOWLEDGEMENTS

The production of the asphalt mixtures, the asphalt specimen and the realization of the dynamic tests at the asphalt was done at the ISBS of TU Braunschweig.

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