Determination of the viscosity of bitumen or mortar measured by the tensile retardation test (ReVis)

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Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.164

ABSTRACT

*Prismatic samples with suitably large dimensions enable tensile retardation tests to measurement the viscosity of bituminous binders as well as the viscosity of mixtures of binder and filler. During the test the sample is put in horizontal positon lying nearly frictionless. In this position the sample is subjected to spontaneous tensile stress. The tensile stress is generated by a unit of stepping motor with transmission. The elongation of the sample is measured by displacement sensors. As the test result the tensile viscosity can be determined. The Diagrams of the logarithmic of viscosity values versus the test temperature indicate a strict linear slope. Noteworthy is, that the viscosity values correlate with the Ring and Ball temperature of pure bitumen grades but not in case of polymer modified bitumen. For pure bitumen, polymer modified bitumen and also for mixtures of bitumen and filler, the viscosity values λZ measured by the tensile retardation test can be describes exactly with the equation log (λZ) = a+b*t. Therefore in case of routine purposes the test can be carried out at only one temperature yielding a characteristic viscosity value. This Value that can be used also as an input for structural design. The viscosity of bituminous mortar measured with the tensile retardation test (called ReVis) provides valuable information on asphalt mix regarding with regard to its resistance to permanent deformation at higher in-service temperatures.*

Keywords: Mastic Asphalt, Mineral filler, Rheology, Temperature susceptibility, Testing

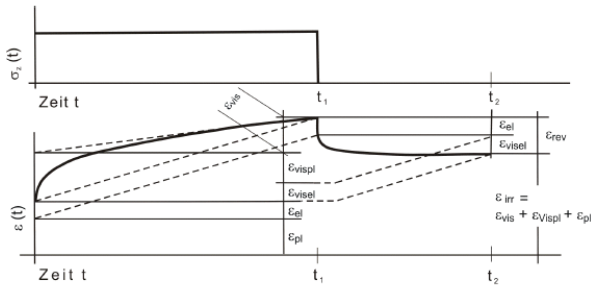
1. INTRODUCTION

The properties of the binder and filler used in road construction directly influence the thermo rheological behavior of asphalt. Therefore, knowing the viscosity and temperature sensitivity of binder and binder / filler mixtures is of particular importance to the forecast of the practical behavior of asphalt concerning the stability in the heat, both, as also the cold flexibility. Numerous test deal exactly with these properties of the binder and with general properties of the filler. Combined trials, which allow a statement by filler / binder mixtures to the resistance of deformation, cold flexibility, aging and susceptibility to cracking, do not exist practically in the testing. The European standardization characterized the stiffening effect of filler in bituminous binders and thus a certain viscosity of the mixture at a corresponding temperature just in the EN 13179-1. To what extent this property the performance of the filler Binder mixture and the subsequent effect of this mixture in asphalt reflects has often attempted to prove. As yet a significant evidence of this relationship could not be demonstrated.

Therefore it is essential to develop tests that more accurately reproduce the rheological properties of the asphalt. Such an test is the tensile retardation test, whereby the effects of the individual components of binders and fillers on the asphalt mortar can be detected as far as to asphalt properties. The tensile retardation test can provide information about the return deformation potential and tensile viscosity of the material.

2. THEORETICAL BACKGROUND

In the examination of asphalt it is of importance, what reactions the material shows under pressure. The complex stress-deformation behavior of asphalt is significantly determined by the influence of temperature. At low temperatures, the elastic deformation shares, at high temperatures predominate the irreversible and so that plastic deformation components. Rheological models attempt to describe precisely these contexts. Each deformation component (Figure 1) can be calculated by equations.



elastic	E_{el}	time-independent	reversible	E_{rev}
plastic	E_{pl}		irreversible	E_{irr}
viscosity	E_{vis}	time-dependent		
visco elastic	E_{visel}		reversible	E_{rev}
visco plastic	E_{vispl}		irreversible	E_{irr}

Figure 1: Definition of the different deformation shares

Simple representatives of rheological models is the so-called Hooke's spring, which can represent only the elastic deformation share as an ideal elastic spring. Thus, a characterization is not sufficiently possible of the material asphalt. Through the implementation of dampers in the model and the extension with additional springs, the rheological behavior of asphalt can be described more accurately. The viscose percentage can be shown via the Maxwell model in addition to the elastic deformation share. Thus the conditions of a relaxation test can be described reliably.

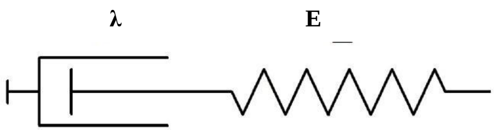


Figure 2: Maxwell model consisting of a series of damper and spring

In addition to the Maxwell model relaxation and retardation tests can be depicted with sufficient accuracy by the Burger's model. The Burger's model is a further development of the Maxwell model and Voigt-Kelvin model, with shock absorber and spring not only in number, but also in addition parallel switched on (Figure 3).

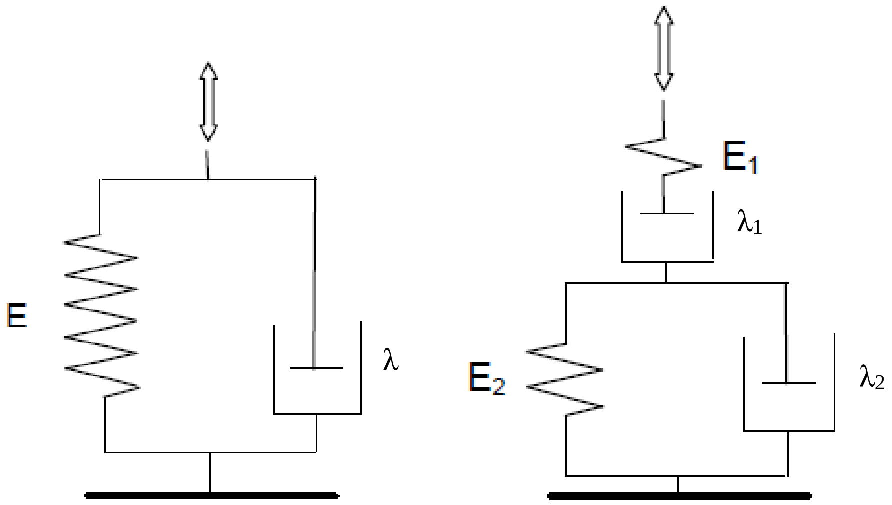


Figure 3: Voigt-Kelvin-(viscos-elastic behavior) and Burger's model

The Burger's model can be formed by using the following formula:

$$\epsilon(t) = \frac{\sigma}{E_1} + \frac{\sigma}{\lambda_1} \cdot t + \frac{\sigma}{E_2} \cdot \left(1 - e^{-\frac{E_2}{\lambda_2} \cdot t}\right),$$

where the first part of the function represents the Maxwell model and the Kelvin-Voigt model describes the second part of the function.

3. DESCRIPTION OF THE TEST METHOD AND THE TEST FACILITY

Centric tensile tests in the form of tension retardation tests have proven to addressing the viscosity and the return deformation potential, which are described in the EN12697-46 (1). In this test, a specimen on a constant voltage level is pulled and held so long until the expansions of the test specimen have a quasi linear progression.

In the framework of the research project "Ansprache des Fließverhaltens von Bitumen und polymermodifizierten Bitumen bei tiefen Temperaturen" (2) the tensile retardation test, described in this abstract, was developed (ReVis), deals by way of derogation from the European norm with the examining of binder and filler/binder mixtures. The research showed that the sample geometry can have a significant effect on the test results. Under the premise that the specimens for tensile tests both the binder and the filler/binder mixture (mortar) are suitable, a rod-shaped specimen geometry was elected with a rectangular inspection cross-section of 1000 mm² and a change to the square surface of the adapter of 1600 mm².

In the tensile retardation test the prismatic specimen of the binder or filler/binder mixture at a constant temperature is subjected to a static load (uniaxial tensile stress) which is applied as quickly as possible and then constant persistent held. In Figure 4 the history of tension and elongation is shown schematically. During the test the axial strain of the specimen is captured depending on time. From the time-strain curve the material characteristic can be determined by applying a value procedure (linear approach, approach to Burger) which determines the descriptive flow material characteristic tensile viscosity.

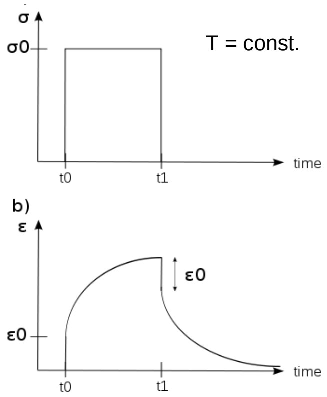


Figure 4: stress and strain gradient of the retardation test

During the research project a special testing apparatus for the examination of binder or mortar lying with nearly friction free sample body storage was developed.
The change in length of the specimen is measured via a transducer with a resolution of 0.1 µm and a maximum deviation (accuracy) of 1 µm. The registration of the tensile force happens via a force transducer with a resolution of 0.01 N and a maximum deviation (accuracy) of 0.5 N. To perform the tests with high accuracy, changes in length can be adjusted by a step motor gearbox with a resolution of 0.02 µm targeted on the sample set.

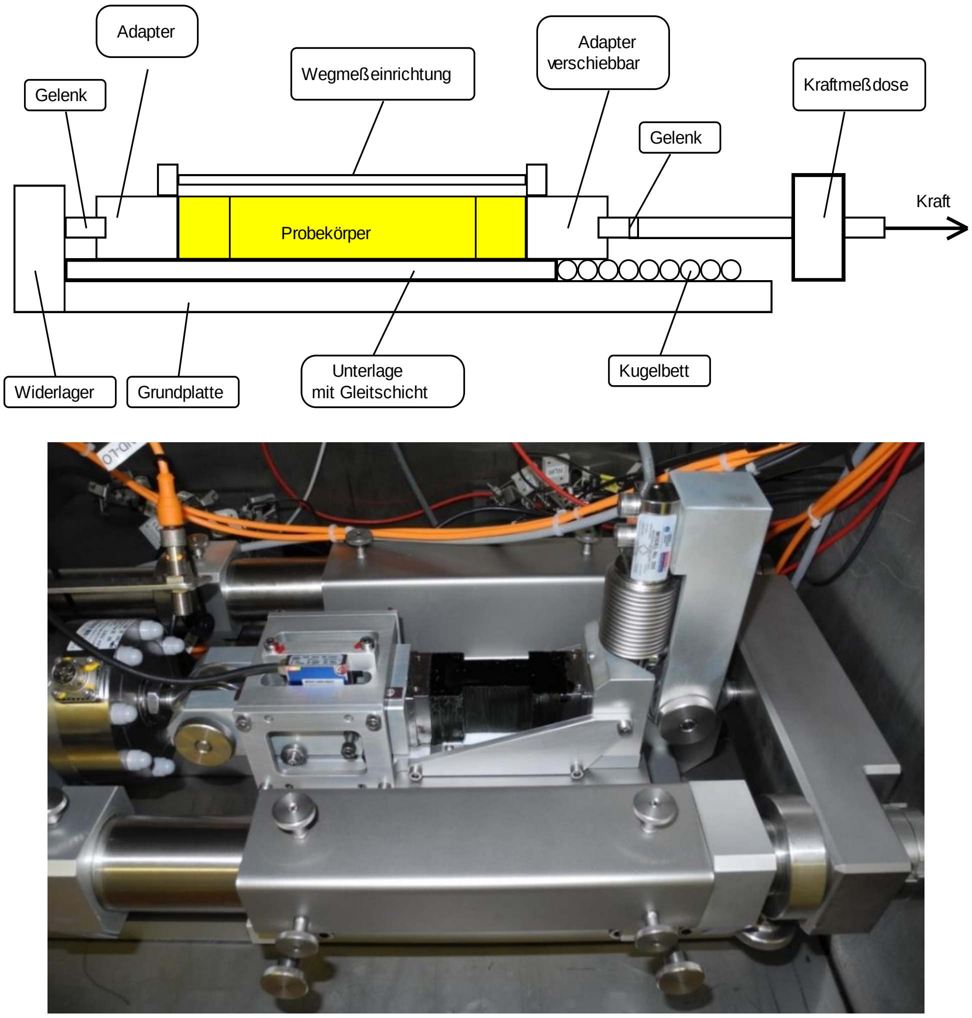


Figure 5: schematic representation of the test set-up and picture of the test rig with the clamped test specimen (2)

The apparatus is located in a cold oven. Thus temperature can be realized from -40 ° C to + 40 ° C with an accuracy of ±0. 3 K. Depending on the sample type (binder or filler/binder mixture) the test temperature is so elected that analyzable time-strain curves exist.

Table 1: Test conditions

test temperature [° C]	sample type	tension [MPa]	load duration [min]	temperature duration [min]
+ 5	binder mixture of filler and binder	0.010 0.100	60	150
5	binder mixture of filler and binder	0.100 0.100	120	150
15	binder mixture of filler and binder	0.250 0.250	240	150
-25	binder mixture of filler and binder	0.250 0.500	480	150

During the test strain, tension and temperature are registered continuously depending on the time over the duration of the test. The test is considered to be completed, if the test conditions in accordance with table 1 are complied or a deformation of the sample is larger than 15 mm. Because it is a tension-controlled test, the controlled force depends on the changing cross-section of the test specimen and is calculated always up to date. Based on the assumption of a constant volume of the specimen, L_0 is calculated from the reference length = 60 mm and the reference cross section $A_0 = 40 \cdot 25$ mm². The tensile force, depending on the changing cross section, is calculated with:

$$F(\Delta l) = \sigma_0 \cdot \frac{V_0}{L_0 + \Delta l} \qquad [N]$$

4. EVALUATION OF THE TENSILE TEST OF RETARDATION

Assuming a constant tension and a constant temperature as well as the knowledge of the history of the time-strain curve of the sample the tensile viscosity can be simplified determined on the slope in the quasi-linear section of the time-strain curve:

$$\lambda_Z = \frac{\sigma}{\dot{\varepsilon}} = \frac{\sigma}{\frac{\Delta l}{\Delta t \cdot L_0}} \qquad [MPa \cdot s]$$

with
- λ_Z tensile viscosity of the binder [MPa·s]
- σ constant uniaxial tensile stress [MPa]
- $\dot{\varepsilon}$ slope in the quasi linear area corresponding to time-strain curve $\frac{\Delta l}{\Delta t \cdot L_0}$ [1/s]
- L_0 effective length (reference length, L0 = 60.0 mm) of the specimen

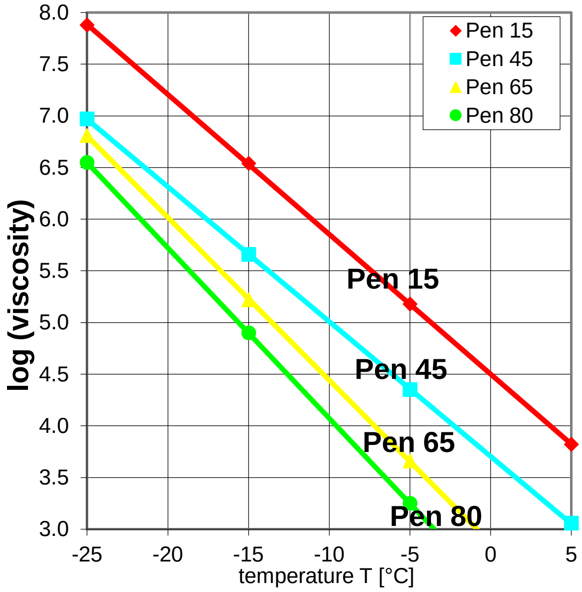
By Application of the Burger's model the three shares of deformation (elastic, viscoelastic, and viscous deformation) can be described through the in the retardation test experimentally captured time-strain relationship for the loading phase.

$$\epsilon(t) = \epsilon_e + \varepsilon_v + \epsilon_{ev} = \frac{\sigma}{E_1} + \frac{\sigma}{\lambda_1} \cdot t + \frac{\sigma}{E_2} \cdot \left(1 - e^{-\frac{E_2}{\lambda_2} \cdot t}\right)$$

with
- ε_e elastic deformation
- ε_v viscous deformation
- ε_{ev} viscoelastic deformation

5. RESULTS

With the mentioned tensions in table 1, viscosities arise with each linear progression in logarithmic representation in the dimension of MPa at the different test temperatures (Figure 6) (3).



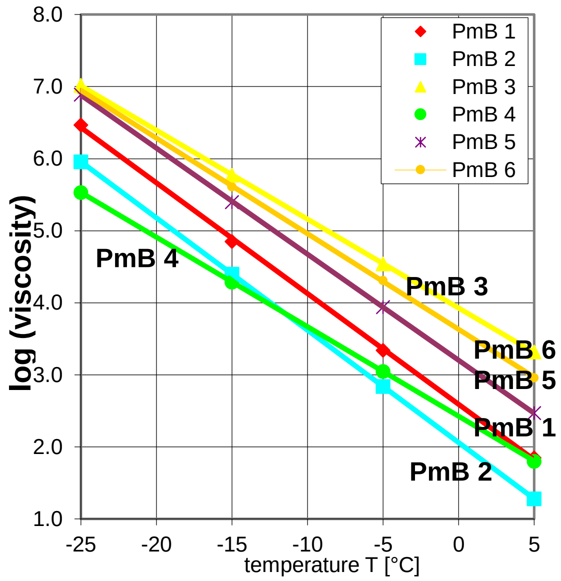


Figure 6: Viscosity of bitumen

The linear dependencies in logarithmic scale show that, to compare the viscosities, the test simplified must be performed only at a temperature. Especially for the characterization of polymer modified bitumen a statement about the actual viscosity can be made, as a replacement for the softening point ring and ball (Figure 7).

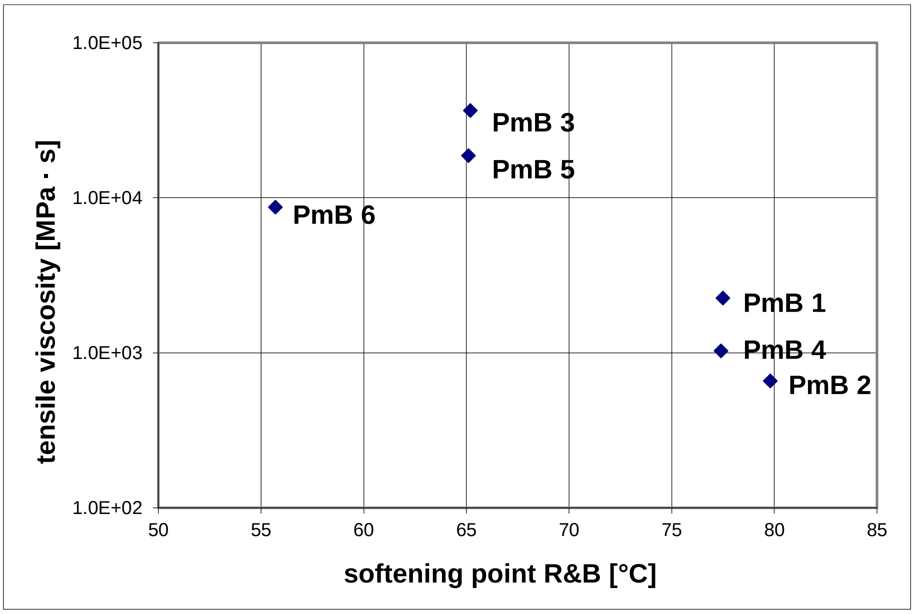


Figure 7: comparison of the viscosities determined in the retardation test at 5 ° C and the softening point ring and ball

In consideration of the test temperatures a significant correlation yields between the softening point ring and ball, as well as the tensile viscosity (Figure 8).

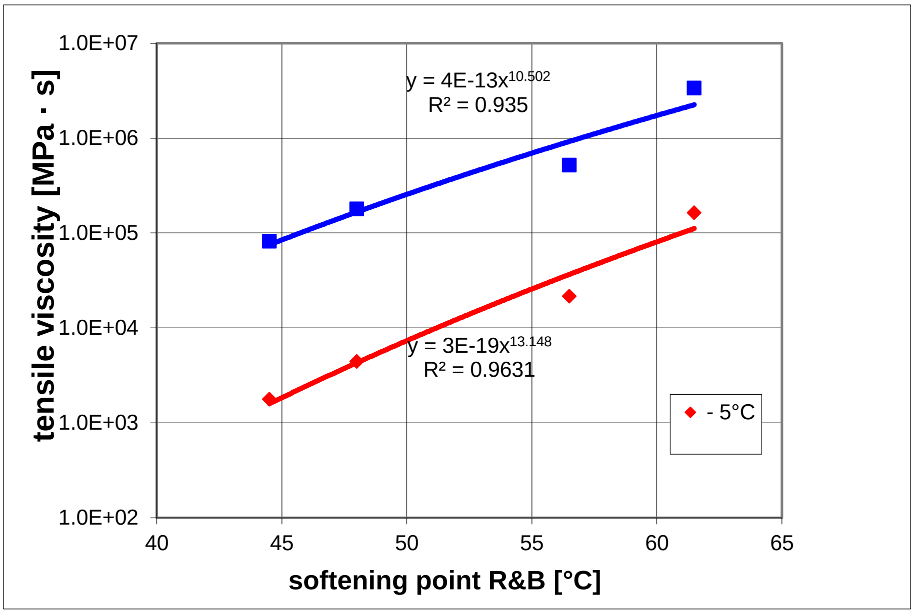


Figure 8: Correlation between the softening point ring and ball and the tensile viscosity in consideration of the temperature

Overall, the results of viscosity measurements of both standard bitumen and polymer modified bitumen follow the principles:

$$\log(\lambda_Z) = a + b \cdot T$$

with a niveau of viscosity at 0°C
b temperature-sensitivity of viscosity
T temperature,
with the parameters, shown in Figure 9.

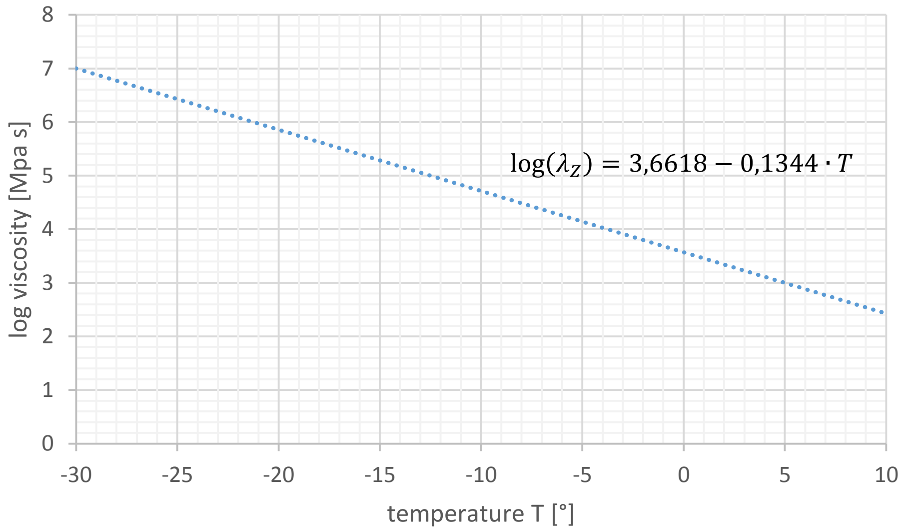


Figure 9: gradient of viscosity as a function of temperature

6. APPLICATION EXAMPLES

In addition to the test of binder viscosities can be detected as well on the mortar. This is especially interesting by using filler- and binder rich asphalt materials such as mastic asphalt (Figure 10). In the context of ongoing researches, a relationship could be proved between the dynamic depth of indentation of mastic asphalt and the viscosity of mortar.

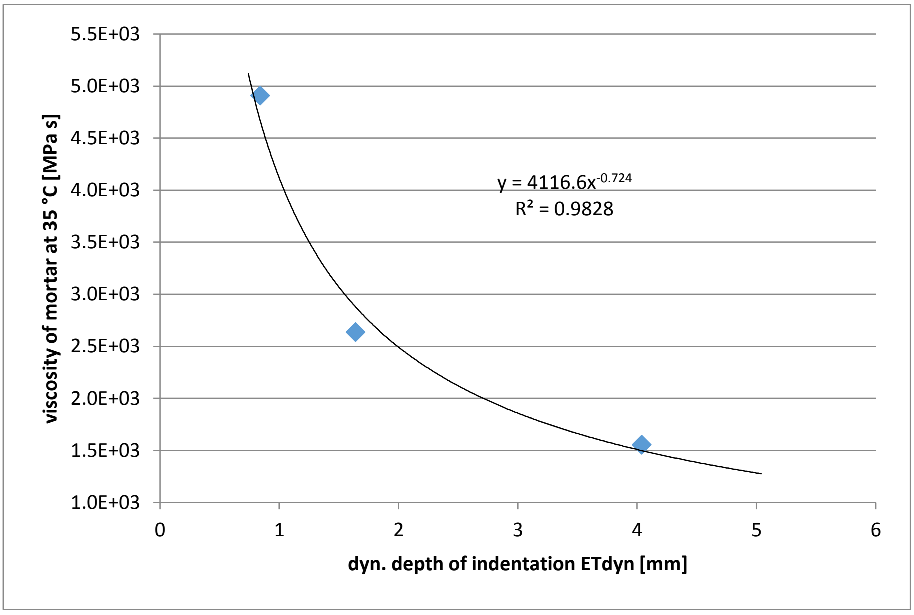


Figure 10: Relationship between dynamic depth of indentation and viscosity of mortar of filler-bitumen mixtures

Based on Figure 10, it can be read that, if the dynamic depth of indentation ET_{dyn} from 4 mm to 1 mm should be lowered, the viscosity of mortar has accordingly to increase at a test temperature of 35 ° C by 1500 MPa·s on 4300 MPa·s. Correspondingly, the filler/binder ratio in the mastic asphalt has to be adapt.

7. CONCLUSION

The developed test, a tensile retardation test with horizontal test specimen called ReVis, to determine the viscosity of binder and mixture of binder and filler, produces plausible results. The plausibility is reflected in the fact, that all results of viscosity measurements on the binder with an r-squared value have a linear progression of 99.5-100% over the respective temperature range with logarithmic scale of the viscosities on the ordinate.

Also another crucial condition meets the new procedure: the determination of the softening point ring and ball has proven itself as a conventional single point viscosity specification for testing of bitumen for decades. The results of the new procedure for the measurement of absolute viscosity must correlate with the softening points ring and ball. This requirement is satisfied with the new procedure of ReVis with an r-squared value by over 96% (test temperature - 5 ° C). By testing the absolute viscosity of polymer modified bitumen there is no link with the softening point ring and ball. As noted in the research behavior (4), the conventional viscosity measurement of softening point ring and ball penetration, etc. fails completely in this case. But with the developed test not only bitumen and modified binders can be tested reliably on viscosity, but also a mixture of binder and filler (mortar).

The tensile retardation tests provide so secured data that binders according to type and quantity and filler according to type and quantity can be selected specifically to pursue high viscosity of mortar, which as demonstrated in the mastic asphalt, points directly on the resistance to thermal distortion. The results of measurements of viscosity in the tensile test of retardation in binders and mortar always precisely follow the principle of $\log(\lambda_Z) = a + b \cdot T$.

The results of basic research over the entire temperature range are so evident, that's completely sufficient for routine tests to identify comparable indicators for modified binders, binders and also asphalt mortar at a temperature such as + 5 °, because of cost reasons, and to underlie the results the dimensioning of pavements.

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