Designation of the viscosity of binder with the tension retardation test

Franz Bommert

Highway construction, Federal Highway Research Institute (BASt), Bergisch Gladbach, Germany

bommert@bast.de

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ABSTRACT

The performance of asphalt by low temperatures is largely determined by the viscosity of the binder respectively the mortar of the asphalt.
The traditional test methods for binder (e.g. ball-draw viscosimeter) are limited to temperatures above the service range of temperature for an asphalt construction. The Dynamic Shear Rheometer (DSR) is limited to temperatures above 30°C whereas the Bending Beam Rheometer (BBR) is limited to temperatures below -10°C and not applicable to mortar. Especially the gap in the temperature of these test methods is very important to characterize the viscosity behavior of binder and mortar over the whole range of the service temperatures, which represent the typical environmental conditions of over the seasons, for an asphalt construction.
Tension retardation experiments seem to be very useful to bridge the gap. They address the low temperature behavior of binder and mortar. With this test method the flow characteristics of binder (pen grade and any modification) and any kind of mortar in the service temperature range, in particular at low temperatures of -25°C can be determined with a high precision, and assessed, via the physically interpretable material characteristics quantity of tension viscosity. Furthermore the present findings indicate the potential of extrapolation the results of the Tension retardation for a prediction of the rutting resistance of asphalt mixtures.
As part of several research Projects, BASt (Federal Highway Research Institute) investigated the effects of different modifications of the binder to low temperature behavior of the binder by the tension retardation test.
This paper is intended to provide a more detailed description of the test method Tension Retardation, selected results and related findings.

Keywords: Low-Temperature, Modified Binders, Rejuvenators, Viscosity

1. INTRODUCTION

There are various test methods available for determining the performance characteristics of asphalt. At the high-temperature end, resistance to deformation is determined using the triaxial test, the cyclic compression test and also the rutting test. At the low-temperature end, there are various tension tests available which are described in the EN 12697-46 standard.
The performance characteristics of asphalt are largely determined by the binder used. Besides adhesion, the viscosity of the binder influences asphalt performance significantly in the service temperature range.
The known testing methods for determining the viscosity of binder agents cover the service temperature range only partially or sometimes not at all. Traditional testing methods for determining viscosity, such as the falling ball viscometer, are suitable for measuring viscosity of up to $1 \cdot 10^8$mPa·s which reflects more the binder's temperature range during processing than its service temperature range.
With the Bending Beam Rheometer (BBR), 3-point bending tests are carried out on bar-shaped specimens with relatively small dimensions. The small dimensions of the specimen combined with the considerable influence of the geometry of the specimen on the test result as well as the low-level forces to which the specimen is exposed and which hence result in only minor deformation must be considered to be negative with this type of testing. In order to obtain reliable results, very precise preparation of the specimens is required here. Sensitive measuring equipment is additionally needed here that is adapted to small forces and deformations.
The application range for the Dynamic Shear Rheometer (DSR) is limited to temperatures of above 30°C. The performance of binders at low temperatures cannot be directly determined using this test method.
Unlike the methods referred to above, the tensile retardation test can be used to measure tensile viscosity from $1 \cdot 10^2$MPa·s to up to $1 \cdot 10^8$MPa·s which occurs during binder testing at temperatures of between +5°C and -25°C. The test principle of the tensile retardation test corresponds to the tensile creep test (TCT) in EN 12697-46.
The following shows the test results for paving grade bitumen, wax-modified paving grade bitumen and a recycled binder that was modified with rejuvenators.

2. TENSILE RETARDATION TEST METHOD

2.1 Principle of the test

In the tensile retardation test, a prismatic test specimen is subjected at a constant test temperature to a static load by way of uniaxial tensile stress that is applied suddenly and then kept constant. During the test, the axial expansion occurring in the test specimen is recorded as a function of time. Taking the time vs. expansion curve recorded, the tensile viscosity as a material characteristic is determined which describes the flow behaviour of the specimen.

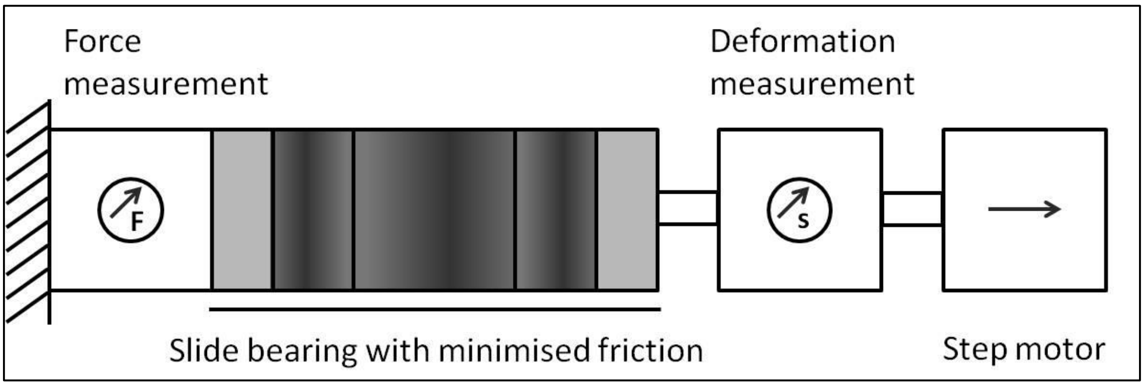

Figure 1: Principle of the test

The development and verification of this test method as well as the definition of suitable test parameters are described in the research report [1] and the publication [2].

2.2 Test set-up

The test set-up for the tensile retardation test is made up of a path measuring system with a resolution of 0.1µm, a load cell with a resolution of 0.01N and a step-motor gear unit that can apply changes in length with a resolution of 0.02µm. The test specimen is placed into the set-up lying down and connected at one end to a rigid thrust bearing and to a pulling device at the other end. Friction on the horizontal contact surface of the specimen is minimised by a Teflon layer and the use of graphite flakes.

The test set-up is fitted in a temperature chamber which controls the test temperature with a precision of 0.5K. The test set-up and temperature chamber are connected via a process computer with a realtime, multitasking operating system and a program for simultaneous capture of measured data, as well as control and process visualisation functionality.
The test set-up for the tensile retardation test is available as an accessory for the tension and cooling-down test set-up for asphalt specimens.

2.3 Specimen

The dimensions of the test specimen are shown in Fig. 2. Due to the geometry of the dumbbell-shaped test specimen with its smaller cross section in the centre, the expansion that occurs under tensile load is limited to a certain area. The tensile zone initially has a cross section measuring 1,000mm².

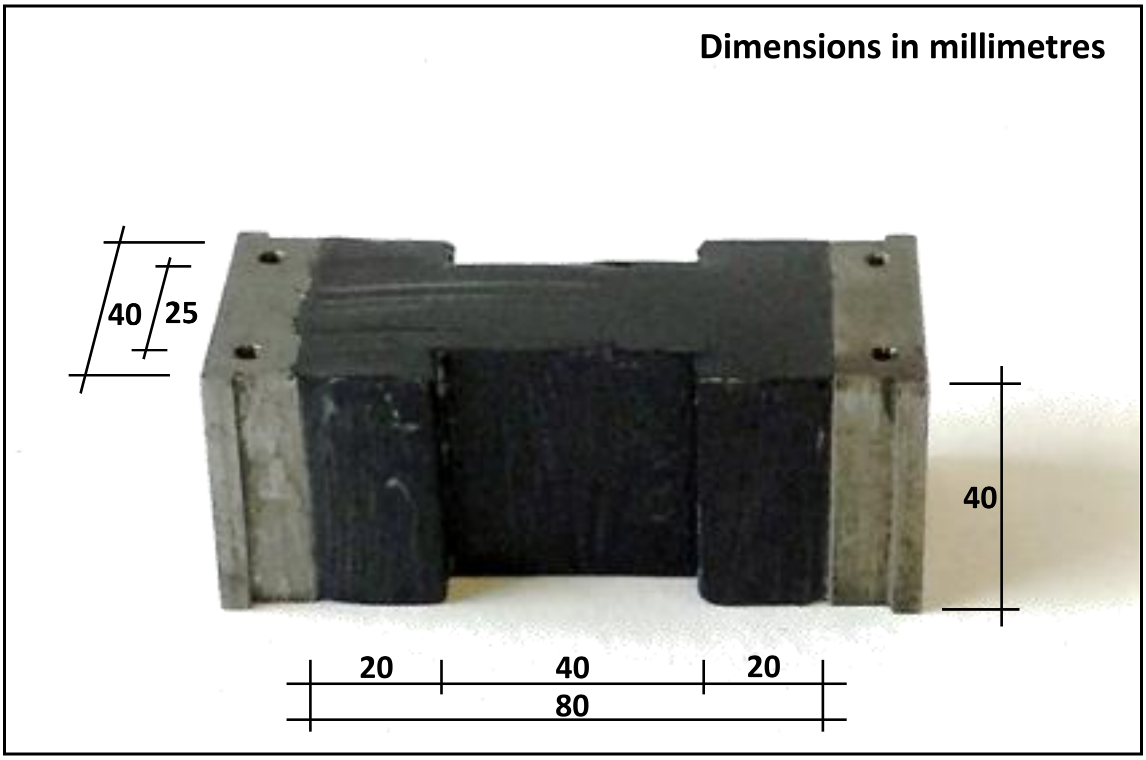

Figure 2: Specimen with adaptor plate

The ends which have a surface of 1,600mm² offer more contact surface for the adaptor plates so that high tensile forces can be applied to the test specimens. The relatively large dimensions and the related large quantities of test material mean that the method for producing the test specimen and fitting it into the test set-up is very easy to master and the test results obtained are very reliable, especially with a view to the necessary load control and the large initial cross-section of the samples.

2.4 Producing the test specimen

Binder portions of 120g each must be prepared while taking into account the portioning allowances and the necessary superelevation of the test specimen during production of the test specimen. The binder must be heated up gently. A temperature must be selected at which the binder can be easily stirred but does not form any bubbles when the test specimen is cast. As a rule, the sub-samples used to produce the test specimen are taken from a larger container. The homogeneity of the sub-samples can be easily assessed using the softening point (ring and ball) test method. The multi-part mould for the test specimen must be coated with a release agent. The adaptor plates are thoroughly degreased and fitted into the specimen mould. The heated and stirred binder is poured into the mould with a small excess quantity. The filled specimen mould is left to cool at room temperature and is then stored overnight at a temperature of 5°C.
Using the same timing (cycle) for the work steps of specimen preparation, specimen production, specimen storage and subsequent testing throughout the entire testing programme, any possible influences on the test results are balanced out and comparable results are obtained.

2.5 Testing

By smoothing and levelling the top surface with a hot spatula, the test specimen is cut to size, shaped and fixed in place in the test set-up by the adaptor plates. The test specimen is then tempered without stress at test temperature for 150 minutes. Following tempering, load is applied. Depending on the test temperature, tensile load is applied which is adapted in terms of stress and duration.

Table 1: Test conditions

Test temperature	Type of sample	Tension	Time tempering	Time testing
[°C]		[M Pa]	[min]	[min]
+5	Binder	0.010	150	60
-5	Binder	0.100	150	120
-15	Binder	0.250	150	240
-25	Binder	0.500	150	480

The applied stress, which is constant in relation to the changing, narrowing cross-section in the tensile zone, causes the test specimen to elongate. After a consolidation phase, elongation increases linearly over the test evaluation time. This linear trend is then used to evaluate the test.

2.6 Evaluation of the tensile retardation test

With constant tensile stress and at a constant test temperature, simplified determination of the tensile viscosity of the binder sample is possible from the time/elongation curve in the linear range.

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

where: λ_Z is the tensile viscosity of the binder [MPa·s]

σ is the constant, uniaxial tensile stress [MPa]

$\dot{\varepsilon}$ is the gradient in the linear range of the time/elongation curve considered for the test [1/s]

Δl is the change in length over the observation period [mm]

Δt is the time of elongation observed [s]

L_0 is the effective length of the test specimen = 60mm (const.)

The individual test results are entered into a diagram with a logarithmic scaling of the ordinate for tensile viscosity and linear scaling of the abscissa for the test temperature. This scaling can be used to map the tensile viscosity curve as a function of the test temperatures with a regression line in the form of

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

where: a is tensile viscosity at 0°C

b is the gradient of the regression line

T is test temperature [°C]

Gradient b of the regression line is an indicator for the temperature sensitivity of the binder.

3. TESTS

3.1 Tests on paving grade bitumen

Fig. 3 shows the tests results for four types of paving grade bitumen from the same manufacturer. The ring and ball softening points of paving grade bitumen are also shown. The results shown in the diagram are plausible. The tensile retardation test provides a differentiated picture of the binder viscosities. Each point represents the result of one retardation test. The regression lines run almost parallel. The gradients of the regression lines reflect the temperature sensitivity of the binders. At different levels, all four types show similar behaviour across the temperature range. All the regression lines show a very high coefficient of determination. The temperature differences of identical viscosities are almost approximately reflected by the temperatures of the bitumen softening points.

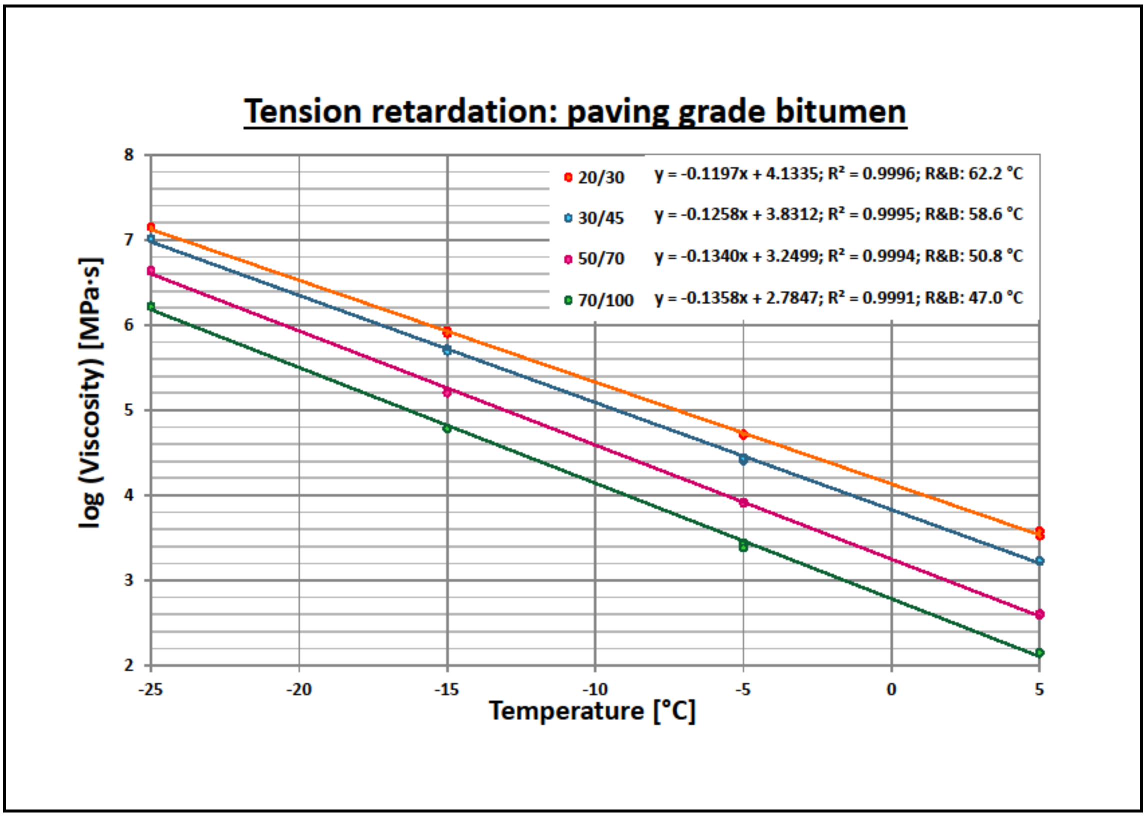

Figure 3: Viscosity of paving grade bitumen

3.2 Tests on wax-modified paving grade bitumen

A FAD (fatty acid derivative) and FTP (Fischer-Tropsch paraffin) were selected for wax modification. Both modifications are used to lower the production and processing temperatures of asphalt. A "soft" paving grade bitumen (70/100) and a "hard" paving grade bitumen (20/30) were each modified with 2% by weight of the additives. The viscosities determined in the tensile retardation test are shown in Fig. 4. The addition of FTP and FAD changes the viscosity of the binders. Unlike with paving grade bitumen, the ring and ball softening point here does not provide a correct characterisation of the viscosity of the binders. The changes in viscosity due to the additive are more significant in the 70/100 binder, both in terms of the increase in viscosity as well as the increase in temperature sensitivity.

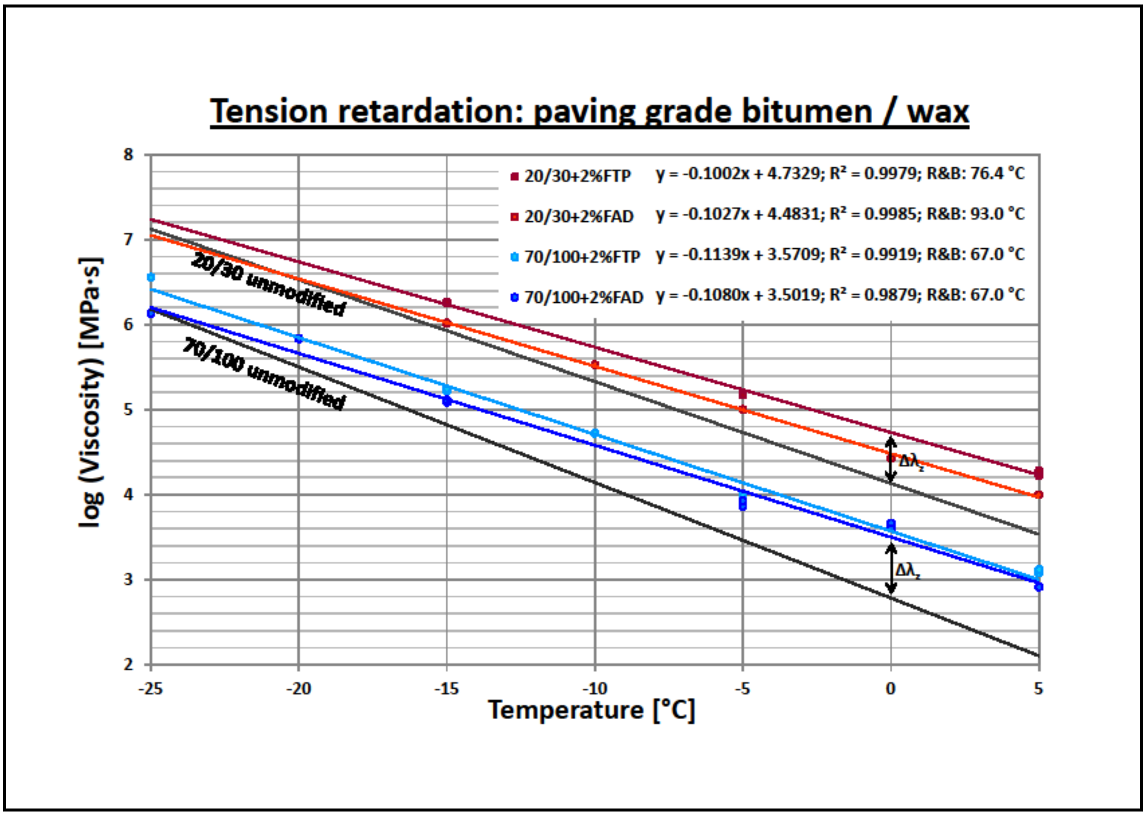

Figure 4: Viscosity of wax-modified paving grade bitumen

The equation for the regression lines shows higher viscosity for all modifications in the 50°C range. This is accompanied by the observation that "wax-modified" binders are more resistant to deformation in the rutting test. The change in viscosity can also be expressed in the equiviscous temperature. In the case of 20/30 paving grade bitumen, modifications for the temperature range around 0°C shift viscosity by 3K to 6K. At 6°C, the FTP-modified paving grade bitumen has the same viscosity as the non-modified bitumen at 0°C. In order to assess these changes in viscosity with a view to the performance of the asphalt layer produced here, the climatic conditions at the place of installation must be taken into account.

3.3 Testing recycled binders and rejuvenators

Recycled binder is made of a reclaimed asphalt pavement (RAP) from a surface course consisting of stone mastic asphalt. More precise details of the RAP are not available. However, a polymer-modified binder, 25/55-55, is typically used for stone mastic asphalt. A sufficient quantity of binder was won from 40 individual extractions of the RAP. Two rejuvenators were used for modification: Rejuvenator 1 (R1) is described by the manufacturer as a mixture of natural resins which in the case of asphalt granulate should restore the original condition of the binder. Rejuvenator 2 (R2) is described by the manufacturer as a "virgin oil for regenerating oxydised binders in reclaimed asphalt". In line with the manufacturer's recommendations, the recycled binder was modified by adding 5% by weight of R1 and 8% by weight of R2, respectively, in relation to the binder. The viscosities determined for the recycled binder (rB) cover the sum of several influence factors: The thermal stress on the binder during production of the asphalt mix, the ageing of the binder over the lifetime of the asphalt layer, interaction with the aggregates of the asphalt mix and the stress resulting from the trichloroethylene solvent during the extraction and the subsequent homogenisation of the many sub-samples which were needed to extract a sufficient sample volume. The viscosities identified in the tensile retardation test are shown in Fig. 5. For reference purposes, the illustration also shows the tensile viscosities of a 25/55-55 binder that is usually used for stone mastic asphalt. The ring and ball softening point is once again not suitable for characterising the viscosity of the binders. The modification leads to a reduction in tensile viscosity in both variants. With rejuvenator 1, the temperature sensitivity of the modified binder also changed. Rejuvenator 2 leads to a reduction in tensile viscosity but not to a change in temperature sensitivity. Comparatively large quantities of both rejuvenators are needed in order to achieve a change in viscosity that corresponds to the range of a 25/55-55 binder.

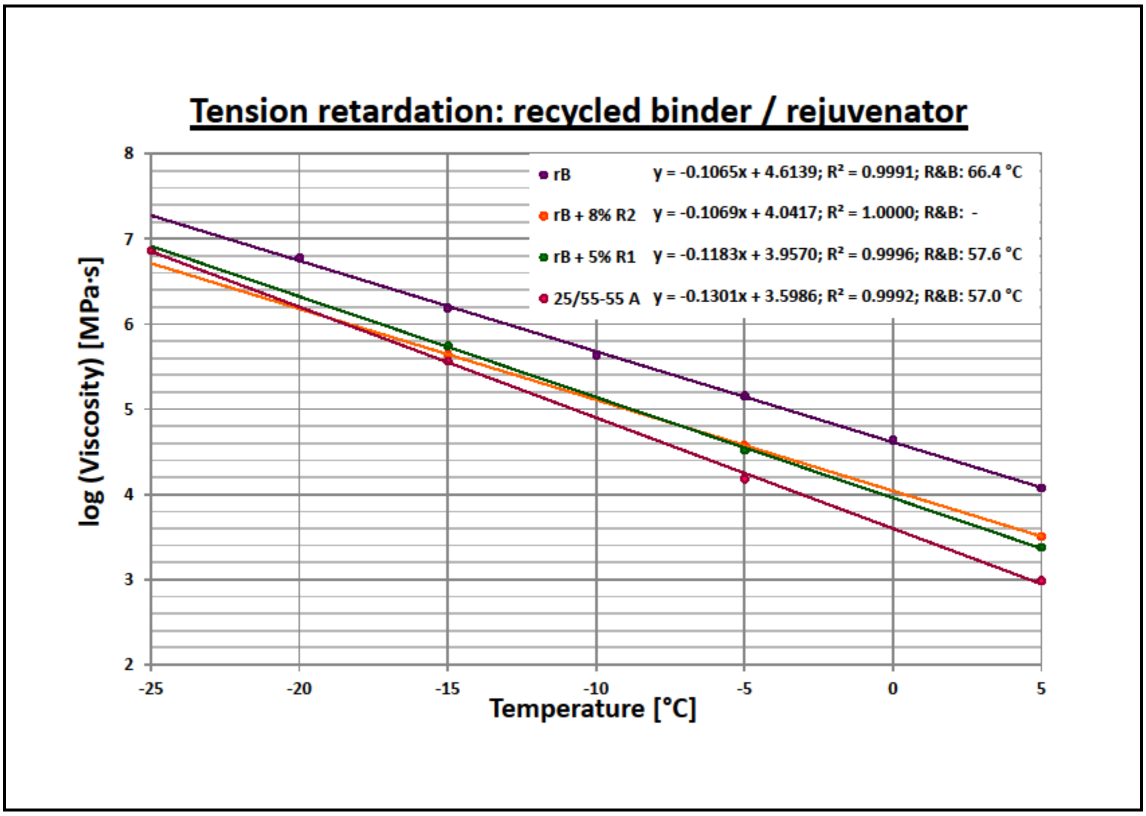

Figure 5: Recycled binder/rejuvenator

4. Summary

The tensile retardation test method can be used to directly determine the viscosity of binders at low temperatures. The regression line represents one measurement for the temperature sensitivity of the binders. With the equation for the function of the regression line, the viscous performance of the binders can also be evaluated in the "hot" service temperature range. Changes in the viscosity of binders due to modifications can be shown very clearly using this test method.

5. Outlook

The test set-up is also suitable for measuring the viscosity of filler-binder mixes [3]. It can be used to record the stiffening effect of different fillers as well as the impact of different filler-binder ratios.
Furthermore, it must be examined whether the tensile viscosities of binders and filler-binder mixes determined with the test method described here
– can be used in analytical pavement design,
– there are correlations with the tension and cooling tests on asphalt.
Recommendations can be developed for the necessary tensile viscosity of an "ideal binder" which meet the climatic conditions that prevail on site. This requires practical application data regarding the tensile viscosity of a binder that has been tried and tested at very low temperatures and the tensile viscosity of a binder that has been tried and tested at very high temperatures. These viscosities characterise two points of the tensile viscosity characteristic that describes an "ideal binder" for this application.

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