A new Binder-Fast-Characterization-Test using DSR and its Application for Rejuvenating Reclaimed Asphalt Binder

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ABSTRACT

A simple method using Dynamic Shear Rheometer is proposed for determining high temperature key parameters of asphalt binders instead of the insufficient Ring-and-Ball softening point. The test was recently introduced in the German standards, and is called "Bitumen-Typisierungs-Schnell-Verfahren (BTSV)", which translates to Binder-Fast-Characterization-Test. It consists of continuous oscillatory DSR measurements in the linear visco-elastic domain while temperature is increased from 20 to 90 °C. As soon as the decreasing shear modulus G* reaches a pre-defined value of 15.0 kPa, the corresponding temperature, called T_{BTSV} and the phase angle δ_{BTSV} are obtained. While T_{BTSV} provides information on material hardness, δ_{BTSV} indicates the degree of modification. Both key parameters form a solid basis for further rheological asphalt binder evaluation, which is exemplarily shown in this study. Ageing (in laboratory and on-site) and blending processes of asphalt binders are resulting in a linear change of these two key parameters, which is used for rejuvenating binder from reclaimed asphalt (RAP).

Keywords: Dynamic Shear Rheometer (DSR), Ring-and-Ball softening point $SP_{R\&B}$, Binder-Fast-Characterization-Test, BTSV

1. INTRODUCTION

In Europe, asphalt binders are mainly characterized through needle penetration [1] and Ring-and-Ball softening point ($SP_{R\&B}$) tests [2]. Often, $SP_{R\&B}$ is the only indicator for evaluating Reclaimed Asphalt (RAP) binder during the asphalt mix design, and hence, limitations for $SP_{R\&B}$ are found in national technical standards for blending and rejuvenating RAP binders [3–5]. However, numerous authors have reported significant problems using the conventional test method of $SP_{R\&B}$ for analyzing complex asphalt binders resulting from the addition of polymers, rejuvenators and RAP binders. As the use of RAP and rejuvenators is increasing due to more sustainable pavement construction, a new test method is needed for rheological binder characterization, especially in binder routine control testing.

2. BACKGROUND AND OBJECTIVE

The first use of $SP_{R\&B}$ test for the identification of the softening of asphalt binders dates back to the year 1926 [6]. The $SP_{R\&B}$ describes the transition between solid and liquid phase of asphalt binders and approximately represents the upper limit of the service temperature of asphalt pavements [7; 8]. Thus, the $SP_{R\&B}$ temperature can be interpreted as a parameter representing a specific material condition. However, the $SP_{R\&B}$ is not a rheological-physical value. Different authors tried to define $SP_{R\&B}$ of plain binders in terms of viscosity or with oscillatory measurements at the corresponding $SP_{R\&B}$ temperature [9–12]. However, no distinct correlation between the rheological parameters and the $SP_{R\&B}$ was observed, especially when modified binders were investigated.

In Figure 1, a variety of binders is presented in a logarithmic scale, having different penetration grades. For the temperature of the $SP_{R\&B}$, complex shear modulus G* was determined in DSR at a frequency of 10rad/s. For all plain binders (70/10, 50/70, 30/45), an average approximate complex shear modulus G* = 15 kPa can be identified, as confirmed by the exploratory findings of Radenberg and Gehrke [10]. However, for polymer modified binders, G* varies significantly and indicates, that the $SP_{R\&B}$ does not provide consistent results. For complex modified binders the determination of the state of the binder softening through $SP_{R\&B}$ is insufficient and inconsistent [13]. It can be stated, that $SP_{R\&B}$ does not satisfyingly represent an equivalent rheological property for polymer modified binders.

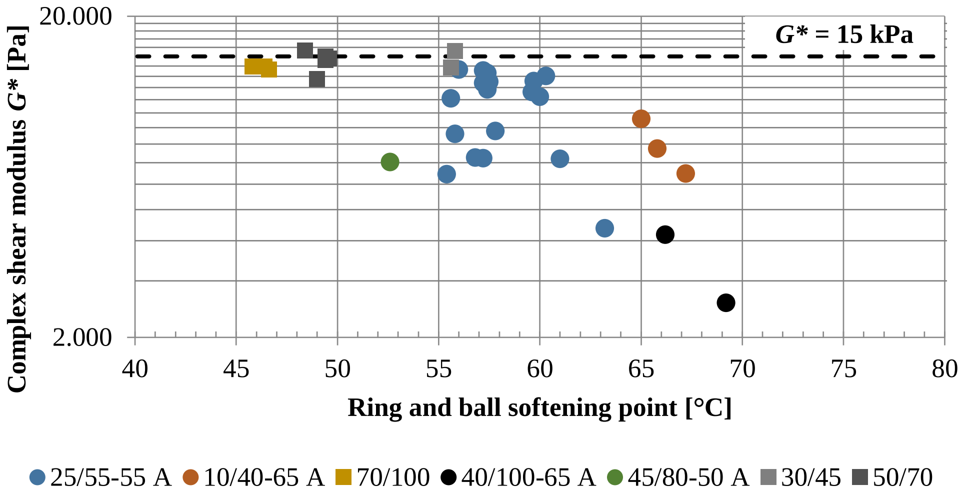

FIGURE 1 Complex shear modulus G*, measured at the softening point temperature $SP_{R\&B}$, with a frequency of 10 rad/s, and a shear stress of 500 Pa, for different asphalt binders [13]

Based on the fact that the DSR device guarantees determination of equivalent rheological material properties, it is used for a novel Binder-Fast-Characterization-Test, which was recently introduced in the German standards, and is called “Bitumen-Typisierungs-Schnell-Verfahren (BTSV)”. Using this procedure, the iso-modulus-temperature corresponding to a shear modulus of G* = 15 kPa, the rheological material behavior of any binder at high temperature is precisely characterized. Advantageously, distinct rheological data are obtained, and moreover, only a small amount of binder is needed, and the test procedure is simple and fast.

3. METHODOLOGY

The Binder-Fast-Characterization-Test (in German: BTSV), is using DSR with a 25 mm plate-plate geometry and a gap width of 1 mm. During the test, binder temperature is continuously increased from 20 °C to a maximum of 90 °C with a temperature rate of ΔT = 1.2°C/min. Therefore, the total testing time is approximately 60 minutes. A constant oscillatory shear stress of 500 Pa (in stress-controlled mode) is applied to the binder sample at a constant frequency of 10 rad/s, which guarantees testing within the range of linear viscoelastic (LVE) behaviour [14] for all binders – without prior determination of the LVE range. During the test, temperature, complex shear modulus G*, and phase angle δ are recorded every 2.5 seconds. The test stops when a default value of G* = 1 kPa is reached.

Exemplarily for a 50/70 pen-grade binder, Figure 2 shows the curves of complex shear modulus and corresponding phase angle in function of temperature. For a complex shear modulus of G* = 15.0 kPa, the key parameters are obtained: the temperature T_{BTSV}, and the corresponding phase angle δ_{BTSV} (where BTSV stands for the German name of the procedure Bitumen-Typisierungs-Schnell-Verfahren).

This Binder-Fast-Characterization-Test (in German: BTSV) has already been examined for a number of more than 1000 binder samples, always providing reliable results in terms of clearly differentiating binder characteristics in the high temperature range. It is thus represented in the German technical standards [15], and is intended to completely replace $SP_{R\&B}$ and needle penetration methods.

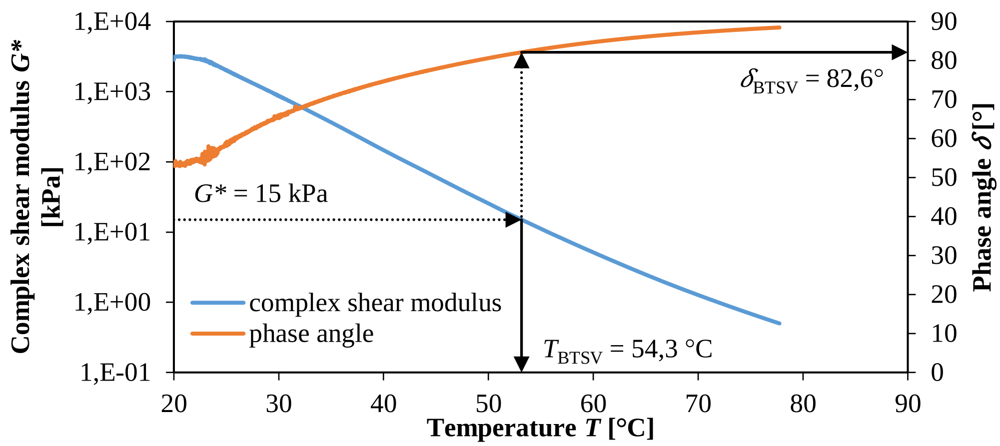

FIGURE 2 Example for determining T_{BTSV} and corresponding phase angle δ_{BTSV} for a 50/70 pen-grade binder from results obtained through the novel Binder-Fast-Characterization-Test (in German: BTSV)

4. TESTING

In this study, the Binder-Fast-Characterization-Test (BTSV) was performed on a number of 175 different asphalt binders, which are classified according to European standards EN 12591 [8] and EN 14023 [7]. Different virgin plain and polymer modified binders produced from different manufactures between the years 2007 and 2015 were included.

For simulating short term ageing of binders, a limited number of the binders was aged at at a temperature of 163 °C through Rolling Thin Film Oven Test (RTFOT) [16]. Aging time was stepwise increased from a standard duration of 75 minutes (1x RTFOT aged), progressively up to a duration of 8 times 75 minutes (8x RTFOT aged). After each aging process, BTSV key parameters, namely T_{BTSV} and δ_{BTSV}, were determined for the aged materials.

5. RESULTS

5.1 Using BTSV for Binder Characterization

Based on BTSV results for plain and polymer modified binders, a characterization system to differentiate the binders based on the temperature T_{BTSV} and on the phase angle δ_{BTSV} can be derived, as shown in Figure 3. Different binders are represented through box-domains, including all the measured combinations of T_{BTSV} and δ_{BTSV}.

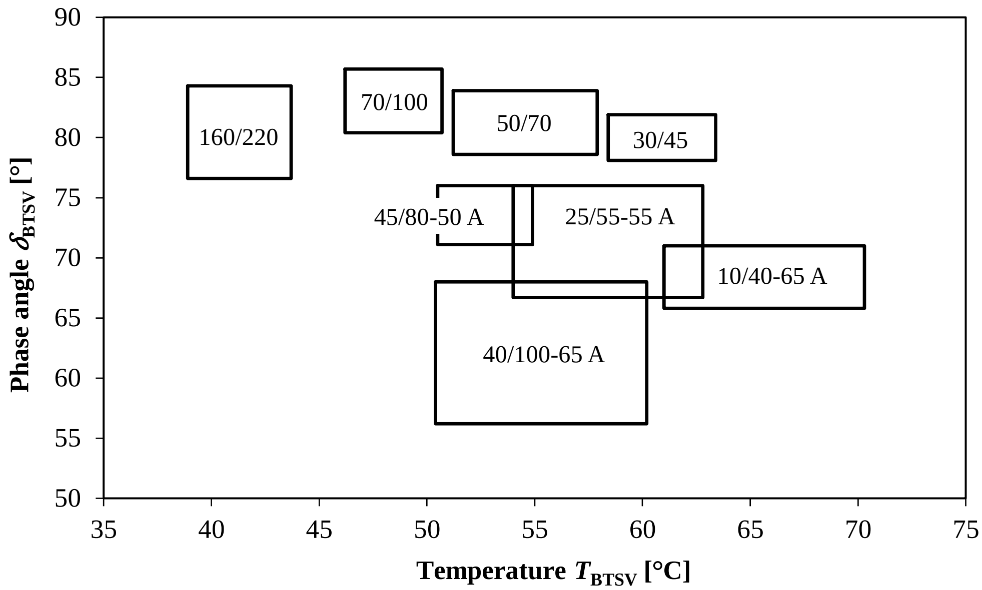

FIGURE 3 Binder characterization based on the Binder-Fast-Characterization-Test (in German: BTSV) for a set of asphalt binders typically used in Europe, and using key parameters: temperature T_{BTSV} and the corresponding phase angle δ_{BTSV}

As shown in the figure, it is observed that plain binders are well differentiated by T_{BTSV}, which provides an indication on the hardness of the binder, while the phase angle δ_{BTSV} provides information on the degree of modification. Low values for δ_{BTSV} are associated with a higher degree of modification, whereas high values indicate less degree of modification. Hence, these parameters can be used for a distinct rheological characterization of different (unknown) asphalt binders in the high temperature range. They form a solid basis for further rheological asphalt binder evaluation.

5.2 Using BTSV for Aged Binder Characterization

Using the data obtained on aged binders at different RTFOT levels, the effects of aging on T_{BTSV} and δ_{BTSV} can be evaluated. Figure 4 presents an example of a plain 50/70 and polymer modified 25/55-55 binders after several RTFOT aging stages. Both the binders present a linear trend with respect to the change in rheological properties due to aging. Based on parameters T_{BTSV} and δ_{BTSV}, specific aging patterns can be identified in form of mathematical functions, which are advantageous to rank binders in terms of aging susceptibility.

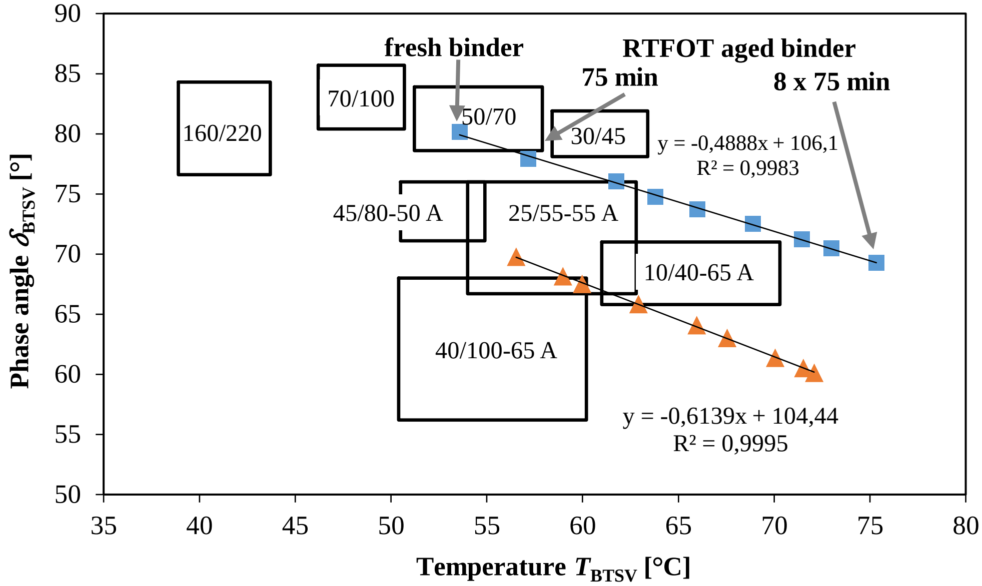

FIGURE 4 Effects of RTFOT laboratory aging (with increased durations) on T_{BTSV} and δ_{BTSV} obtained with the Binder-Fast-Characterization-Test (in German: BTSV) for plain 50/70 and polymer modified 25/55-55 A binders

5.3 Using BTSV for Binder Rejuvenating

Furthermore, the BTSV can also be used for evaluating aged binder from RAP and during rejuvenating and blending processes. In Figure 5, an extracted polymer modified binder from RAP is presented and mixed with different proportions of two rejuvenating materials (160/220 and chemical rejuvenator). Depending on the proportions of aged and fresh binder, the properties of the resulting bituminous blend will always take a position along the 'blending line' expressed by parameters T_{BTSV} and δ_{BTSV}. The first blending line demonstrates the blending of the aged binder with a 160/220 pen-grade binder. Depending on the amount of fresh binder added, the bituminous blend can show rheological properties of a 25/55-55 A or a 50/70 binder. The second blending line shows the change in rheological properties when adding a chemical rejuvenator to the aged binder. Compared to the blending with virgin asphalt binders, much less amount of material is needed to change the rheological properties. However, the blending line runs horizontally and the blending with this certain rejuvenator can only change the hardness (T_{BTSV}) but not the state of modification (δ_{BTSV}).

Based on these results, the BTSV can be used to evaluate the effect of different rejuvenating materials on the rheological properties of aged asphalt binders. The blending lines cannot only indicate which target asphalt binders can be produced by using certain rejuvenators. They can also identify the necessary amount of rejuvenator needed. This could be very useful in the recycling procedure to produce target binders blended with RAP binder with specific target properties.

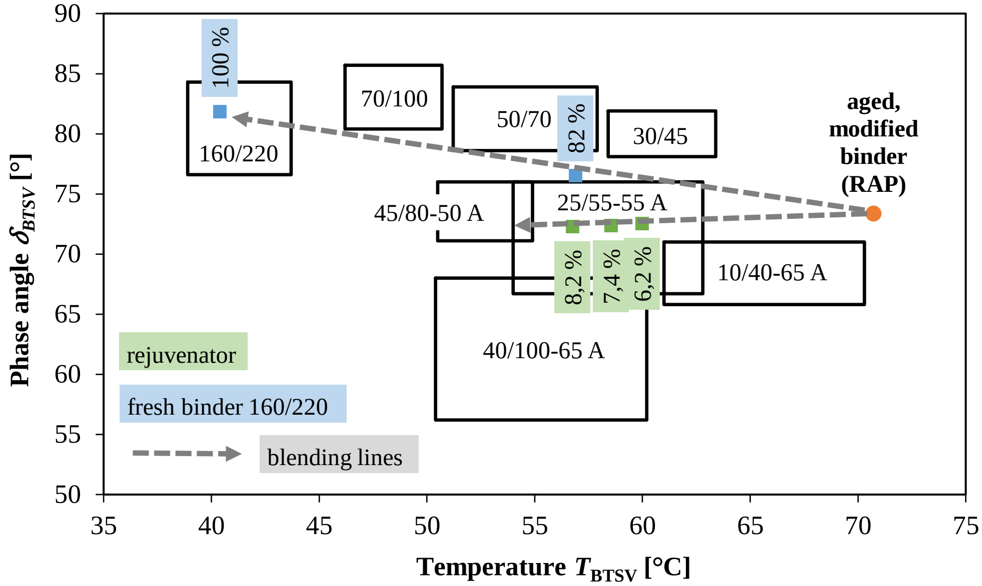

FIGURE 5 Example on using the blending line based on BTSV parameters obtained with the Binder-Fast-Characterization-Test (in German: BTSV)

5. CONCLUSIONS

In the present work, a new procedure based on DSR measurements was proposed in order to replace the traditional Ring and Ball softening point ($SP_{R\&B}$) method and to differentiate binder characteristics in the high temperature range. The procedure is called Binder-Fast-Characterization-Test (BTSV) (Bitumen-Typisierungs-Schnell-Verfahren, in German). It consists in performing a DSR test at low constant shear stress in the LVE range over a temperature ramp. Two key parameters were chosen as the result of the test: the temperature, T_{BTSV}, as an indicator for the binder hardness that can be considered a surrogate of the $SP_{R\&B}$ parameter and the corresponding phase angle δ_{BTSV}, which provides additional information on the possible degree of modification.

Using this procedure, a characterization system for common binders used in Europe was proposed allowing a simple grading of the materials and showing the influence of polymer modification. In addition, the effect of laboratory aging and blending of fresh and extracted RAP binder on the two key parameters was investigated. In particular, a linear trend of the phase angle δ_{BTSV} versus the temperature T_{BTSV} was found in both cases. Both trends can be expressed with a mathematical equation and thus help in evaluating the binder extracted from RAP and in determining the optimal amount of additives or virgin binder for blending.

The presented method is a simple, rapid and robust test procedure, which needs very small amount of binder. The BTSV represents a successful alternative to the $SP_{R\&B}$ approach for differentiating (unkown) asphalt binders in the high temperature range.

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