Binder performance and testing

New possibilities of assessing bitumens temperature sensitivity and aging

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Abstract

Use of dynamic shear rheometers (DSR) to characterize aging susceptibility of paving grade and polymer modified bitumens (PMB) is commonplace at research centres and universities. In spite of the huge volume of research devoted to this topic, there are differences in the profession how to transform the complexities of their behaviour into relatively simple specifications. That is why the development of performances related specification is progressing slowly in Europe. The current Czech specification for paving grade bitumens CSN 65 7204 from 2016, included the recommendation to measure the binder temperature sensitivity using temperatures T1 and T2 as typical values. Temperature T1 is evaluated when G* = 5 MPa while temperature T2 is evaluated when G* = 50 kPa. Both parameters are assessed after short term aging using Rolling Thin Film Oven Test (RTFOT). The Czech specification CSN 65 7222-1 for PMB from 2017 included also the determination of temperatures T3 and T4 for the same specified stiffness values as for T1 and T2 after long term aging using Pressurized Aging Vessel (PAV) equipment. The above mentioned parameters were evaluated for a group of paving grade bitumens and PMB obtained from various bitumen producers at middle European market. All samples were tested at authors´ laboratories. Pertinence of the approach in above mentioned norms is discussed and compared with recent developments in USA and in Europe. Based on the data measured and on information from literature an alternative more simple procedure to assess binders' aging susceptibility is proposed. This methodology/testing procedure would allow technicians to determine binder temperature sensitivity using G* as a direct parameter without the need to manipulate the data via interpolation as it is required now.

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1. INTRODUCTION

Lot of research on bitumen temperature sensitivity and aging has been carried out. There are still differences in the profession how to transform the complexities of their behaviour into relatively simple specifications.

In the course of the revision of harmonized standards EN 12591 (paving bitumens) and EN 14023 (polymer modified binders) has been suggested to include the parameters based on DSR (Dynamic Shear Rheometer) measurements. It allows the assessment of the temperature sensitivity and the impact of binder aging via using functional parameters instead of empirical ones which are used currently.

The evaluation of binders from DSR in relation to the temperatures for specified rheological parameters (that is after temperatures T1 to T4) has been proposed in case of polymer modified binder. However, only temperatures T1 and T2 remained for paving bitumens. Based on the data measured and on information from literature an alternative simpler procedure to assess binders' aging susceptibility is proposed hereafter.

More sophisticated methods for the evaluation of binders' aging are for example Glover - Rowe and Viscoelastic Transition (VET) methods. Some notes on these two methods are given in the paper. Recently implemented linear amplitude sweep test (LAS) is also briefly mentioned. The chart with used methods and approaches described within the paper is depicted in Figure 1.

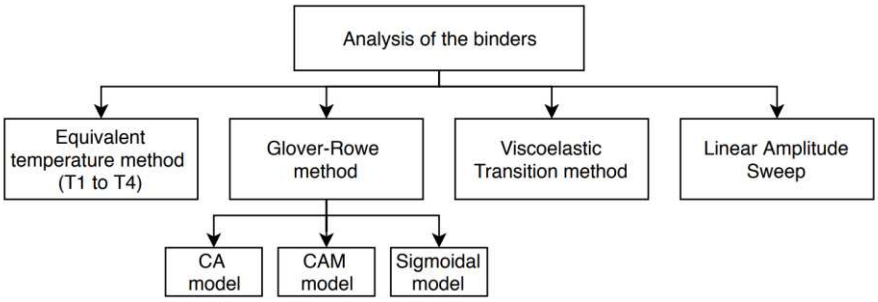

Figure 1 Methods discussed in the paper

2. EVALUATION OF BINDERS' AGING BASED ON TEMPERATURES T1 TO T4

The modulus G* = 5 MPa and 50 kPa for the test frequency 1.56 Hz were selected for the determination of temperatures T1 and T2 for the binders aged by RTFOT (Rolling thin film oven test after EN 12607-1). The specified stiffness G* = 50 kPa for the temperature T2 was chosen to correspond closely to the temperature at the softening point R&B of fresh nonmodified binders (used traditionally for classification purposes in binders' specification).

During the preparations of the new European norms for PMB classification it has been accepted to include also binder tests after PAV (Pressure ageing vessel after EN 14769). Thus the temperature T3 and T4 were added. The same stiffness limits were proposed for the evaluation of the temperatures T3 and T4 on the binder after RTFOT + PAV aging. Temperatures T3 and T4 have already been implemented in the Czech national's norms for the classification of PMB (ČSN 65 7222-1 in 2017 [1] and in ČSN 65 7222 2 and 3 in 2018 [2] and [3]. The difference T3-T1 and/or T4-T2 could indicate the impact of the long-term aging. Overview of the testing conditions is given in Table 1. The testing is carried out within the linear viscoelastic region.

Table 1 Boundary conditions for measuring temperatures T1 to T4 in the Czech norms and drafts of EN

Temperature	G* for f = 1.59 Hz @ T_i	Aging	Diameter of plates
T1	5 MPa	RTFOT	8 mm
T2	50 kPa	RTFOT	25 mm
T3	5 MPa	RTFOT + PAV	8 mm
T4	50 kPa	RTFOT + PAV	25 mm

Note: Phase angles are to be recorded as well

The classification of binders according to the temperature for specified stiffness is similar to the American system of Performance Grades (PG). The criterion of PG system for the high temperature domain (HT) was G*/sin δ ≥ 1.0 kPa for fresh binder and G*/sin δ ≥ 2.2 kPa after aging in RTFOT. It was described in the edition of AASHTO M320 [4]. However, this criterion has been replaced in some US states by the assessment based on Multiple Stress Creep Recovery Test (MSCR) for the design temperature evaluated from the climatic conditions in the region. The procedure is given in AASHTO M 332-14 [5]. The binder is classified into 4 categories according to the performance in MSCR at the selected design temperature. The annotation "S" "H" "V" and "E" stands for standard, high, very high and extremely high traffic loading. It is questionable in our opinion if the principle of the assessment based on temperatures for specified values of a certain parameter is really convenient for the implementation in Europe now when in US its use for the classification of binders is declining. The classification based on performance for selected typical temperatures can be more comprehensible for common users.

The application of the difference T4 –T2 for the evaluation of impact of aging is analogue to the idea of expressing impact of aging by the increase of the softening point R&B temperature after PAV. However, if the stiffness of the binder is tested in DSR it is more suitable to express the impact of aging directly by the increase of the binder stiffness. That is why it is better in our opinion to use the Aging index (AI) defined as the ratio of G* after and before considered aging instead of the difference in temperatures. If the PAV aged binder is tested in the future at T1 and T2 temperatures instead of determining T3 and T4 by interpolation between measured values for different temperatures the testing time will be shorter. Moreover, the interpretation of the impact of aging will be simplified and more straightforward. Another problem related to the use of T1 to T4 is that the difference between T2 and T4 is usually only few degrees. Thus, the distinction between different binders is not clear.

It is necessary in our country to respect recently issued national standards. But the impact of aging on the change of the stiffness can be approximately evaluated from declared values of T1 to T4 as presented here.

It is possible to assume that the relation between G* and temperature is linear on semi-logarithmic scale in the range of 5 MPa to 50 kPa. The isochrones are curved for temperatures lower than T1 (or T3) and higher than T2 (or T4) as can be seen in Figure 2. The same behaviour was obtained in various publications for example in the dissertation of Airey [6]. Even a slight curvature of isochrones near T1 and T3 would have only a small impact of the aging index determined with the assumption of linearity in the range of 5 MPa to 50 kPa. In order to limit the impact of possible curvature we determined the aging index by interpolation for temperatures T3 and T2 and not for T1 and T4. We calculated also an average aging index AI_p. It represents approximately the binder stiffness increase due to PAV aging in the range of G* 5 MPa to 50 kPa. The procedure is illustrated in Figure 3.

Measured temperatures T1 to T4 for a set of twelve different 50/70 paving grade bitumens are given in Table 2. Aging indices and temperature sensitivity is also calculated. Temperatures T1 to T4 for three different PMB are shown in Table 3. The graphical interpretation of measuring temperatures T1 to T4 for one particular PMB 45/80-65 (2#) is given in Figure 3. The temperatures at which the aging indices are to be measured are represented by crosses.

High aging index from results at high temperatures does not usually lead to the problem in practise, but high aging index at medium or low temperatures means that the binder can be brittle which leads to cracks in asphalt pavement. The average aging index could mask the problems at medium or low temperature. Thus the application of aging index at T3 is preferable over average AI.

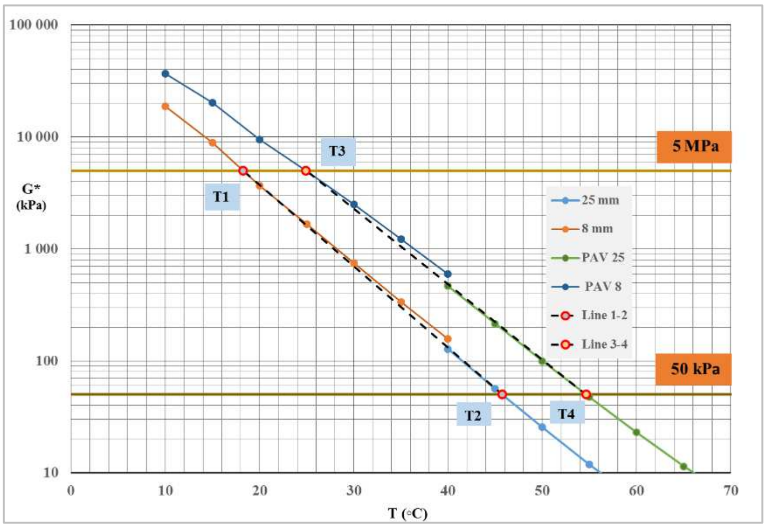

Figure 2 Evaluation of T1 to T4 for a paving grade bitumen 50/70

Table 2 Calculated temperatures T1 to T4 along with aging indices (proposed procedure), 50/70

	Calculated Temperatures				Aging Indices				
No.	**T1**	**T2**	**T3**	**T4**	**T3-T1**	**T4-T2**	**AI @T3**	**AI @T2**	**AI Average**
1	17.1	42.7	22.3	50.2	5.2	7.5	**2.6**	3.4	3.0
2	17.3	49.3	23.8	59.5	6.5	10.2	**2.5**	3.7	3.1
3	18.3	45.0	24.0	52.8	5.7	7.8	**2.7**	3.5	3.1
4	18.2	41.3	24.0	50.7	5.9	9.3	**3.2**	5.0	4.1
5	17.9	44.3	23.3	53.6	5.4	9.3	**2.6**	4.1	3.3
6	18.3	45.8	24.8	55.0	6.5	9.2	**3.0**	4.1	3.5
7	19.5	45.6	25.4	55.0	5.9	9.4	**2.8**	4.3	3.6
8	17.5	47.5	24.1	59.3	6.6	11.8	**2.8**	4.7	3.7
9	16.9	46.6	25.1	55.7	8.2	9.1	**3.6**	3.9	3.7
10	17.7	46.0	23.8	55.8	6.1	9.8	**2.7**	4.1	3.4
11	16.4	46.6	23.3	57.1	6.9	10.5	**2.9**	4.2	3.5
12	15.3	43.6	22.3	52.4	7.0	8.7	**3.1**	3.8	3.5
Ø	17.5	45.4	23.8	54.8	6.3	9.4	**2.9**	4.1	3.5
±	1.1	2.2	1.0	3.0	0.8	1.2	0.3	0.5	0.3
min	15.3	41.3	22.3	50.2	5.2	7.5	2.5	3.4	3.0
max	19.5	49.3	25.4	59.5	8.2	11.8	3.6	5.0	4.1

Table 3 Calculated temperatures T1 to T4 along with aging indices (proposed procedure), PMB

Binder designation	**PMB grade**	Calculated Temperatures				Ageing Indices				
		T1	**T2**	**T3**	**T4**	**T3-T1**	**T4-T2**	**AI @T3**	**AI @T2**	**AI Average**
1#	45/80-60	14.8	42.4	20.1	51.3	5.3	8.9	**2.4**	3.7	3.0
2#	45/80-65	17.3	44.8	21.4	50.9	4.1	6.3	**2.0**	2.6	2.3
3#	25/55-60	17.4	48.3	23.3	58.7	5.9	10.4	**2.4**	3.8	3.1

It is worth noticing that all AI at T3 for paving bitumens are higher than AI for tested PMB. This might indicate a better resistance of PMB against aging. The collection of the test results for T1 to T4 organised by the Czech road administration is under way now. This will allow the verification if our results correspond to those from the broader database.

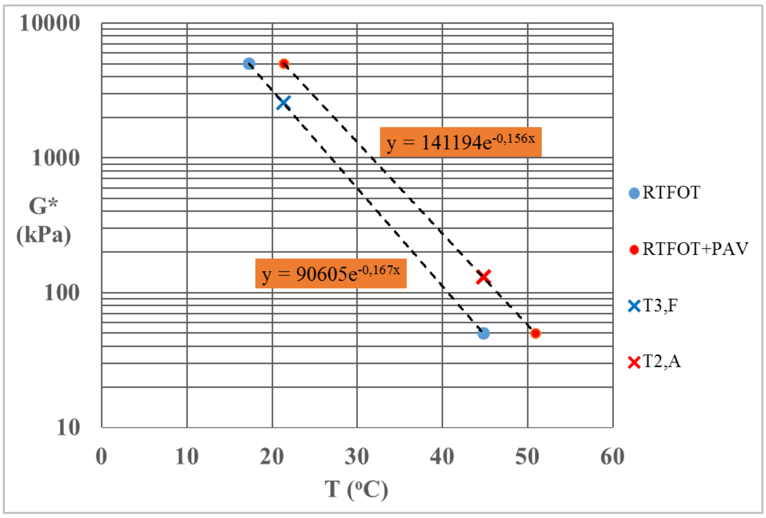

Figure 3 Determination of aging index for PMB 45/80-65 (2#)

3. NOTES ON MORE SOPHISTICATED METHODS FOR ASSESSING BINDER AGING

Glover - Rowe method

Principles of this method and the reasons for its use are described in the literature. Recent summary with references to older papers is described in [7]. That is why the method is referred here very briefly. Glover defined the parameter G′/(η′/G′) as "DSR Function". Rowe recommended converting "DSR Function" into a new form, in which viscosity is replaced by the phase angle (δ). Complex shear modulus (G*) at 15 °C and reduced frequency of 0.0008 Hz is applied. Parameter calculated by the formulae 1 is often called GR after its authors

$$GR = G_{15}^* \times \frac{(\cos\delta)^2}{\sin\delta} \qquad (1)$$

It is a coefficient for assessment of binder behaviour at medium or low temperatures that includes similar binder characteristics as those used in PG binder specification.

Rowe recommended to measure G* at 3 temperatures (for example 5 °C, 15 °C and 25 °C) and at a couple of frequencies in order to be able to construct a partial master curve for the reference temperature T_{ref} = 15 °C and evaluate G* at very low frequency 8E-4 Hz. We call it here Glover-Method and the calculated modulus is referred to as $G^*_{G\text{-}R}$.

We carried out the measurements for the two PMB (1# and 2#) at 5 different temperatures 10 °C, 15 °C, 20 °C, 25 °C and 30 °C for the frequencies f = 0.1 Hz, 1.6 Hz and 10.0 Hz after RTFOT and PAV aging. Firstly, master curves from all measured values were constructed by using different methods described in literature and modulus $G^*_{G\text{-}R}$ were calculated. Secondly, calculation of $G^*_{G\text{-}R}$ from 3 and then from 2 temperatures only was carried out. The results were compared to those obtained from 5 temperatures.

Methods used for the master curves creation were CAM, CA and sigmoidal models. Principles and comparisons between these models are for example described in [8], Formulas of WLF, Arrhenius and quadratic one with 2 regression parameters were employed as well as minimisation without functional relationship for the shift factor SF similarly as in [9]. Master curves and shift factors SF = log(a_T) were calculated with Solver of Excel. We used very low input value of G^*_{min} to assure that the extrapolated modulus $G^*_{G\text{-}R}$ will be still in the straight part of sigmoidal curve. Calculated modulus $G^*_{G\text{-}R}$ after RTFOT and PAV of the aged PMB binder (1#) obtained by various methods described above are given in Table 4. Annotation "SIG min" means sigmoidal model without functional relationship for the shift factor. Differences between methods are relatively small with the exception of CA model which is approximate for very low frequencies, as it is well known. Thus CA method should not be normally used for the evaluation of $G^*_{G\text{-}R}$ in spite of its advantage that calculation can be made manually very quickly without the use of Solver. All other methods can be used to obtain $G^*_{G\text{-}R}$. The shift coefficient for quadratic method with 2 parameters is given by Equation 2.

$$\log a_{(T)} = a_0\,(T - T_{ref})^2 + b_0\,(T - T_{ref}) \qquad (2)$$

This formula seems to us to be more practical than frequently used WLF method as parameters a_0, b_o have a clear geometric meaning which is not the case for 2 coefficients in the WLF formula.

Table 4 Calculated $G^*_{G\text{-}R}$ and Aging index for $G^*_{G\text{-}R}$ (PMB 1#)

Method	RTFOT	PAV	AI (PAV/RTFOT)
CAM WLF	28.9	143.9	5.0
CAM Q	29.6	144.4	4.9
SIG WLF	28.9	144.1	5.0
SIG Q	30.8	144.4	4.7
SIG Arrhenius	33.5	148.8	4.4
SIG Min	32.6	147.2	4.5
CA	24.4	154.3	6.3

The master curves for RTFOT and RTFOT+PAV aging calculated by the CAM WLF method from 5 temperatures are presented in Figure 4 together with measured values after RTFOT+PAV.

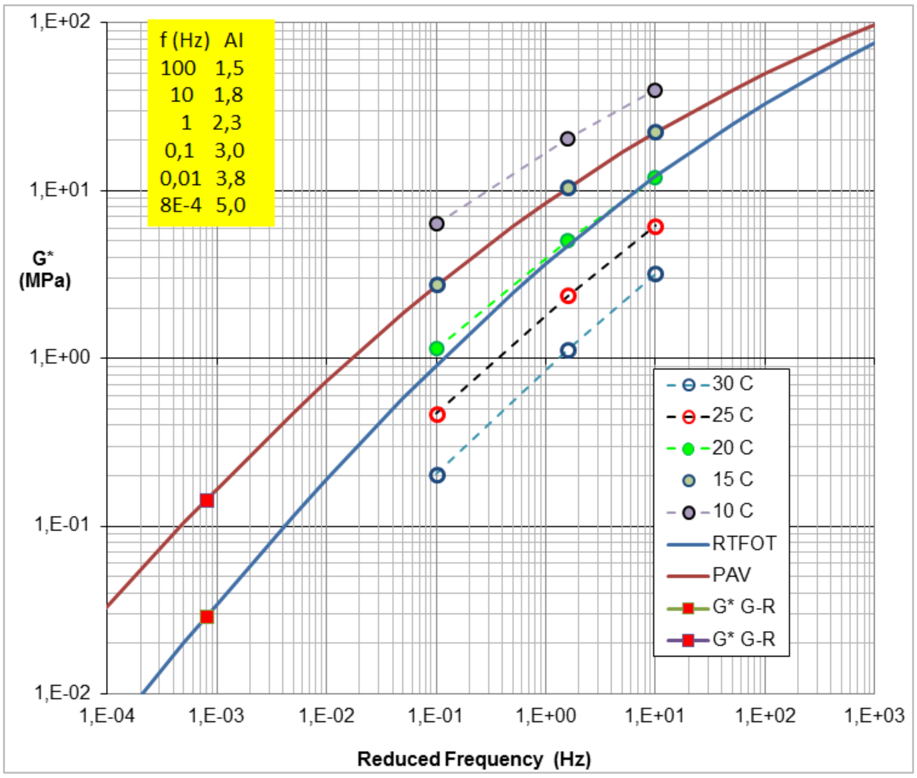

Figure 4 Master curves at T_{ref} = 15 °C after RTFOT and RTFOT+PAV aging for PMB 1#

The global aging index can be calculated by comparing G* for different temperatures. The surface between both master curves for different aging conditions established from a broader range of test temperatures and frequencies can be used as an indicator of aging as recommended in [10]. However, this demands more testing time. The approximate comparison of the aging behaviour of different binders can be obtained from partial master curve as proposed by Rowe.

The AI in Table 4 for very low frequency is higher than AI for f = 1.6 Hz used for the evaluation of T1 to T4 temperatures (Table 2 and 3). It corresponds to the basic principle that the increase of binder stiffness due to the aging is more important for very low frequencies and/or very high temperatures.

The master curve has one inconvenience. The viscous part of the behaviour represented by the phase angle δ is not shown. The presentation in the Black space permits to see both components G* and δ. The impact of aging can be presented for various measured frequencies and temperatures in a Black space diagram. It is useful to present results for different temperatures with different colours connected by full or dotted lines (see Figure 5). This way of presentation enables to visualise that the change of G* and δ due to aging is distinctly greater for low temperatures and high frequencies than otherwise.

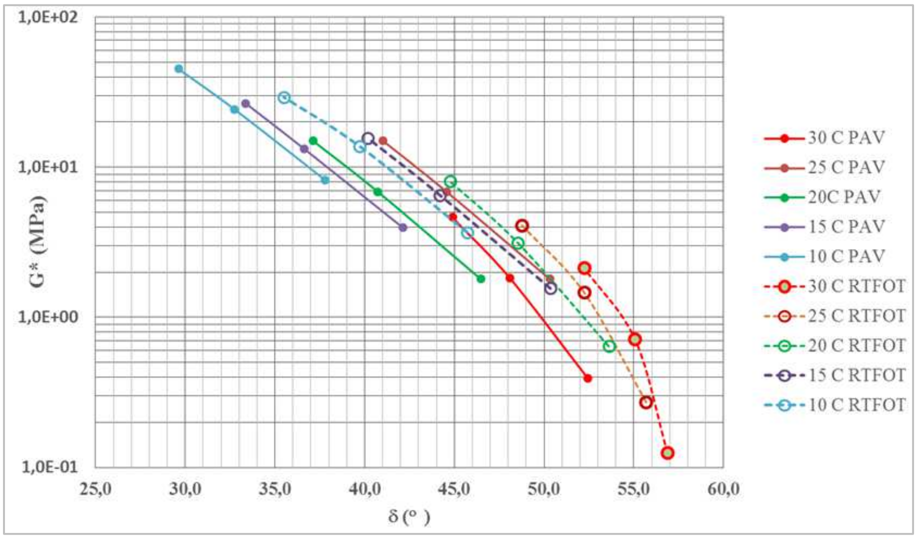

Figure 5 DSR results for 25/55-60 for the range of 10 °C to 30 °C and f = 0.1, 1.6 and 10.0 Hz in Black space

Extrapolation using Glover-Rowe method permits to represent the binder behaviour in Black space for very low frequencies corresponding to the change of stress in the pavement due to changes at low and medium temperatures.

Results of the evaluation of two PMB (25/55-60 3# and 45/80-60, 1#) by the Glover – Rowe method are presented in Figure 6. It is compared with the results of one 50/70 paving grade bitumen and one recycled binder (R1) quoted from [11]. Limits proposed by Rowe (180 and 600 kPa) are also shown. Two methods with the highest difference (CAM WLF and SIG Arrhenius) are presented for PMB 45/80-60 (1#). The difference of a few percent is nearly non-detectable on the graph. This confirms that both CAM and sigmoidal method can be used for the presentation of the results in the Black space diagram.

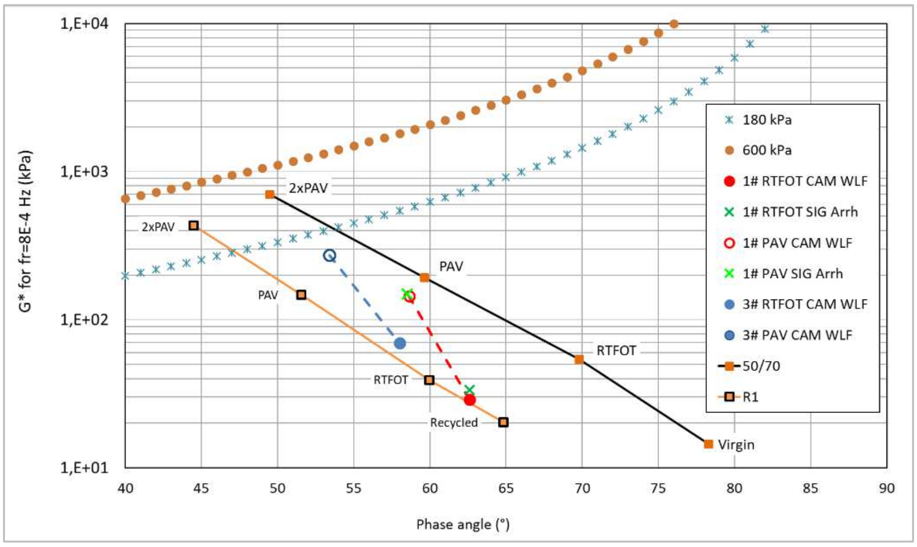

Figure 6 Comparison of PMB, paving bitumen and recycled binder in the Black Space by the G-R method.

Even if the increase of stiffness after PAV is very important for low frequencies, the viscous component changes only a little. Note that the G-R threshold curves depicted in the Black Space diagram must be understood as an indication of possible crack formation, not as a definite classification criterion. A study [12] not only employed the approach devised by Rowe (2012), but also evaluated the G-R parameter at different temperatures by considering equal stiffness of asphalt binders.

However, it is evident from Figure 6 that the aging behaviour of PMB is better than for paving bitumen and recycled binder. The phase angle decrement is smaller for PMB. Higher phase angle after aging means higher viscous component which is preferable for low and medium temperature as the binder relaxation due to the decrease of the temperature in pavement is quicker and stress increase lower. The G-R parameter calculated according the formulae (1) could be added to the points presented in the Figure 6 or given in tables. The evolution of calculated G-R parameter due to aging has the advantage over evolution of AI, as it includes viscous component as well. Naturally both parameters can be presented on the test protocols.

One general remark on the construction of a master curve is included in our notes to G-R method. It is well known that the input parameters for non-linear regression analysis can have an impact on calculated results. Sometimes it is recommended to start the analysis for all binders with the same input values. We usually applied a different procedure to avoid the impact of inadequate input values and/or repetitive calculation. At first we calculate with Solver the shift to master curve with Arrhenius formula. It has only one unknown parameter and input values have only very small impact on the calculated master curve and shift curve. As a next step we use the method without the equation for shift coefficients. Input values are selected in such a way that the shape of the curve is slightly more curved then the shift curve for Arrhenius. The shift coefficients for measured temperatures are usually not located on a smooth curve after regression analysis in the second step. In the third step the input parameters for quadratic method are selected to be close to previous results. (We used for this procedure the abbreviation AMQ according to 3 steps of the calculation).

After analysis of master curves from 5 test temperatures we tried to eliminate measurements at some temperatures to see the impact on calculated $G^*_{G\text{-}R}$. Results are as follows. The master curves and $G^*_{R\text{-}G}$ for 3 temperatures corresponded well to the curves constructed on the basis of 5 temperatures. Even when we constructed master curve from 2 temperatures only (15°C and 30°C) the results were satisfactory. It is shown on figure 7 for PMB 45/80-60 (1#) after RTFOT. Master curves were constructed using sigmoid with quadratic shift. The small difference is due to the fact that shifted points for 30 °C are not far away from the location of $G^*_{G\text{-}R}$. Temperatures 15°C and 30°C are sufficiently apart to enable the correct construction of the part of the master curve in which we are interested in. Naturally, the difference between both curves will be greater for very high and very low frequencies.

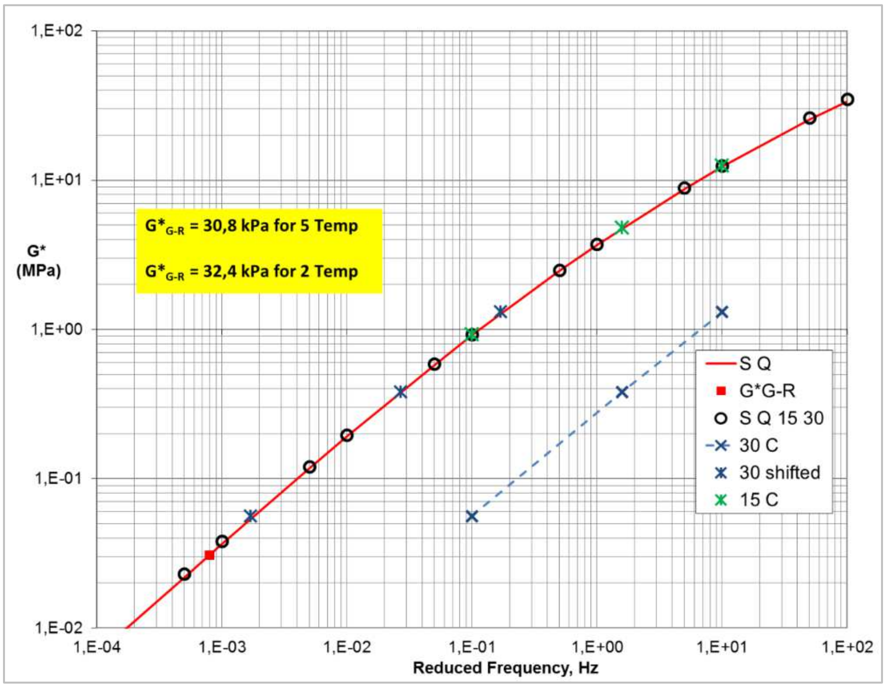

Figure 7 Comparison of master curves constructed from 5 and 2 temperatures PMB 1#

That is why we think that the use of temperatures 15 and 30 °C with 3 or 4 frequencies in the range 0.1 to 10.0 Hz is sufficient for common evaluation of the impact of binder aging with Glover-Rowe method. Naturally, if for some reason more exact analysis is needed more test temperatures can be applied.

Viscoelastic Transition method (VET method)

An assessment of the binders' behaviour at intermediate temperatures can also be carried out by using the viscoelastic transition temperature (VET). This approach was introduced by Migliori [13] and further developed by Widyatmoko [14]. VET is defined as transition temperature when the phase angle value reaches 45°. Therefore, the elastic component of the complex shear modulus G' is equal to the viscous component G'' of the complex shear modulus. Complex shear modulus at T_{VET} is defined as G^*_{VET}. Over aging T_{VET} is increasing as binder become more elastic and G^*_{VET} is decreasing. Later Porot and Eduard [15], based on this methodology, suggested classification of the aged binder based on measuring T_{VET} and G^*_{VET}. Their proposed classification is given in Table 5.

The results of T_{VET} and G^*_{VET} in relation to aging of paving bitumens No. 1 to 12 are displayed in Figure 8. The Figure includes the regression curves for different binder condition, i.e. unaged, RTFOT and RTFOT+PAV. The evolution of concerned parameters over aging is depicted directly for bitumens no. 2, 4 and 5. These binders were chosen purposely with the aim to show that difference in T_{VET} in unaged condition can be for various binders within a small range whereas in case of G^*_{VET} the difference can be much greater. Generally, it can be said that all binders meet the requirements for 50/70 paving grade bitumen in terms of penetration and ring and ball even though that the functional behaviour as depicted in Figure 8 can differ substantially even for unaged binders.

Table 5 Classification matrix for the degree of aging function of cross-over parameters [15]

G^*_{VET} (Pa)	T_{VET} (°C)		
	0 to 20	20 to 40	40 to 60
$>10^7$	--	+/-	
5×10^6 až 10^7	+	++	+++
10^6 až 5×10^6	++	+++	++++

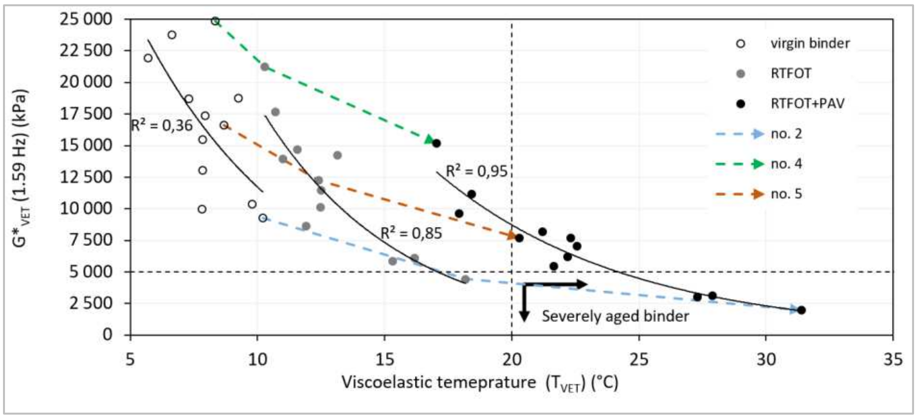

Figure 8 The evolution of VET and G_{VET} in relation to aging, 50/70 paving grade bitumens

Linear Amplitude Sweep Test (LAS method)

Linear Amplitude Sweep Test was proposed in USA by Bahia and Johnson in 2010. It was later published as AASHTO TP 101-14 with the latest edition in 2018. The draft of AASHTO TP 101-14 "Estimating Damage Tolerance of Asphalt Binders Using the Linear Amplitude Sweep" can be downloaded from internet [16]. That is why details are not presented here. The LAS test includes an oscillatory strain amplitudes sweep to induce fatigue damage at an accelerated rate. Frequency sweep test is normally run before the amplitude sweep test on the same specimen to obtain a fingerprint of the material's undamaged material response. Viscoelastic continuum damage theory (VECD) is used for the evaluation.

The maximum shear stress was used as a failure criterion at first. New interpretation of the test was proposed by Castorena [17]. It was used later on in various papers and on the dissertation of Safaei [18]. That is why we use here the acronym C-S evaluation method for this approach. According to C-S evaluation method, failure in LAS is defined based on the peak in stored pseudostrain energy.

The released pseudo strain energy represents the difference between the total pseudo strain energy (undamaged response) and stored pseudo strain energy (damaged response). Released pseudostrain energy can be used for the calculation of the G^R coefficient proposed recently by Wang for the evaluation of the fatigue resistance potential of bituminous binders. [18]. We used VECD for evaluation of LAS test, but it is out of the scope of this text.

However, the impact of binder aging on LAS test behaviour can be approximately evaluated without calculation of pseudostrain energy and sophisticated VECD theory as proposed by Eckmann [19]. The failure according to C-S evaluation method of VECD is located at the start of the steep decrease of the measured shear stress. It is shown in Figure 9 for the paving bitumen 50/70 and in Figure 10 for PMB 25/55-60 (3#). Tests were carried at 15 °C. This is the equivalent design temperature in the Czech or French pavement design method.

The paving bitumen was stiffer than PMB at this temperature. PAV aging caused higher shear stress during LAS test. Maximum shear stress was obtained earlier after RTFOT The decrease of shear stress from the peak value was more important after PAV. The strain at failure after C-S method was slightly higher. Similar behaviour was obtained for PMB. Main difference was much greater strain at failure for PMB than for 50/70 bitumen. It demonstrates much better fatigue resistance of PMB. Another important aspect is that the shape of the stress strain curve of PMB is less influenced by aging than for paving bitumen. Similar behaviour was obtained for tests at 20 °C, but the peak shear stress was not so pronounced.

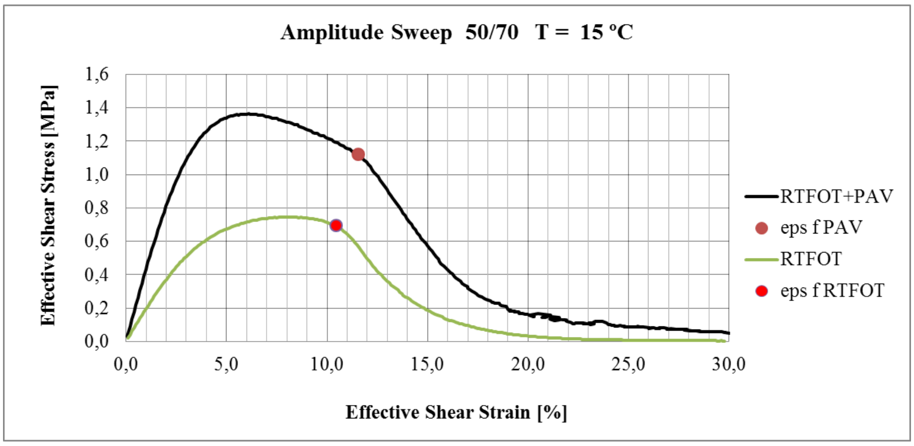

Figure 9 Impact of aging on the binder behaviour in LAS test for road bitumen 50/70

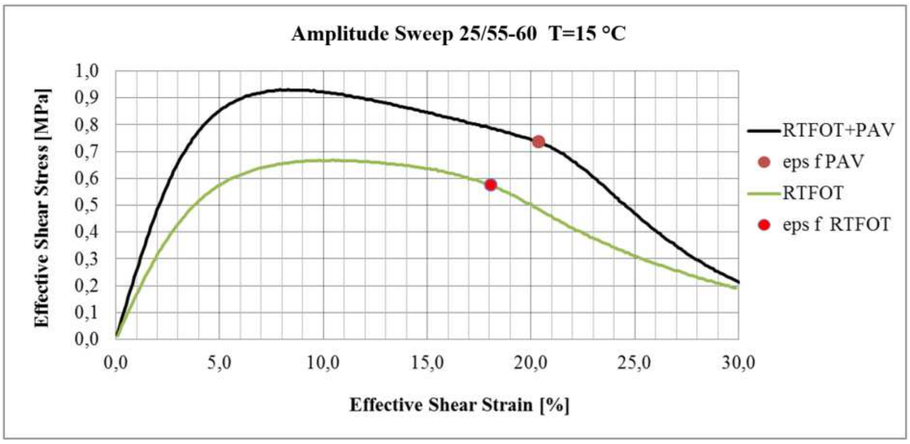

Figure 10 Impact of aging on the binder behaviour in LAS test for PMB

4. CONCLUSIONS

The determination of temperatures T3 a T4 after PAV aging for G* = 5 MPa and 50 kPa was proposed to the future EN 14023 „Specification framework for polymer modified bitumens" In our opinion it would be better to measure in the future the G* after PAV aging at temperatures T1 and T2. The binder sensitivity using G* as a direct parameter can be obtained without the need to manipulate the data via interpolation as it is required now. Instead of spending time with measurement for 2 or 3 temperatures close to each other, the measurement can be carried out for 2 temperatures further away- for example for temperature T1 and T1 + 15 °C. It would allow to construct partial master curve using the Solver function of Excel (or similar software tool) and calculate parameter $G^*_{G\text{-}R}$ after RTFOT and PAV. This will permit deeper insight to the impact of aging on binder properties as simple difference T3-T1 as proposed at present.

If the determination of T3 and T4 will remain in the norms in the future, the approximate evaluation of the aging index from the declared T1 to T4 can be done as proposed in this text.

G-R method and presentation of results in the Black space enables to visualise clearly the changes in the behaviour of binder due to aging. Differences between binders can be better detected than after the procedure proposed in the draft of EN for PMB. Partial master curve for the calculation of $G^*_{G\text{-}R}$ can be constructed with reasonable precision from temperatures 15°C and 30 °C for paving bitumen and common PMB. As some highly modified bitumen do not have simple rheological behaviour more test temperatures and frequencies will be needed to describe their behaviour.

The LAS method permits also to compare and evaluate approximately the impact of aging and differences in the behaviour of aged binders. Simple comparison of maximum shear stress and the strain after which an abrupt decrease of the shear stress starts, is sufficient for common use. This was demonstrated on one example. If more precise analysis is needed in some cases, the sophisticated viscoelastic continuum damage method (VECD) can be applied.

The use of these methods in a simplified way presented here can help to pave the gap between advanced theoretical studies and the state of mind of people used to the old empirical tests and evaluations.

The VET method can also be used to get an idea about the impact of aging. It has the advantage of simplicity due to testing at one frequency only. The fact that the complex modulus G^*_{VET} decreases with aging is logic, but the increase of the $G^*_{G\text{-}R}$ with aging is more comprehensible for common users without the detailed knowledge of the binder rheology.

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