CETRA[2018]

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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CETRA 2018
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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CETRA 2018 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

LOW TEMPERATURE PROPERTIES OF PAVING GRADE BITUMEN

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Abstract

Research into the low temperature cracking in asphalt pavements is an important priority in asphalt laboratories worldwide. In such laboratories the low temperature cracking process is simulated on asphalt samples using several different types of tests. Due to the fact that the resistance of asphalt to low temperature cracking depends mainly on the used bitumen, it is assumed that this process can be indirectly predicted with knowledge about the realistic low temperature properties of bitumen. For many years the properties of bitumen at low temperatures have been determined based on the Fraass fracture temperatures. Since the Fraass breaking point test has several shortcomings, additional parameters like stiffness and creep rate were introduced in the Bending Beam Rheometer (BBR) method, which has been standardized but it is still not widely used. The characteristic of B 70/100, which is frequently used in Slovenia for asphalt production, has not been tested yet. Six samples of bitumen B 70/100 were extensively tested. The purpose of the study was to determine the impact of aging on the paving grade bitumen B 70/100 used in our region, and to propose criteria for bitumen quality based on evaluation of obtained test results. On neat bitumen the usual scope of bitumen tests (R&B, Penetration, Fraass) was performed as well as BBR and DSR tests. These bitumens have been laboratory aged with RTFOT method and all tests were repeated on short term aged bitumens. In the last step the six bitumens have been laboratory aged with RTFOT and PAV method and then re-tested. In the paper, the sensitivity to laboratory aging for six samples of B 70/100 produced by six manufacturers, is presented and analyzed.

Keywords: low-temperature, rheology, bending beam rheometer, bitumen ageing

1 Introduction

Research into the low temperature cracking and fatigue in asphalt pavements is an important priority in asphalt laboratories worldwide. Due to the fact that the resistance of asphalt to low temperature cracking depends mainly on the bitumen, it is assumed that this process can be indirectly predicted with knowledge about the realistic low temperature properties of RTFOT and RTFOT+PAV aged bitumen. For many years the properties of bitumen at low temperatures have been determined based on the Fraass fracture temperatures. Since the Fraass breaking point test has several shortcomings, additional parameters like stiffness and creep rate were introduced in the Bending Beam Rheometer (BBR) method, which has been standardized but it is still not widely used in Europe. The DSR measurements of complex shear modulus (G*) and phase angle (δ) were introduced to evaluate the bitumen resistance to high and to low temperatures. Six samples of bitumen B 70/100 produced by six producers were extensively tested. The purpose of the study was to determine the impact of aging on the paving grade bitumen B 70/100 used in our region with the emphasis on the low temperature resistance after laboratory aging.

2 Asphalt temperature changes

During asphalt production the bitumens are subjected to high temperatures up to about 180 °C and therefore undergo hardening during this process. After laying and compaction, they are subjected to daily and annual cycles of temperature, especially high temperatures in summer and low temperatures in winter. The daily temperature changes in asphalt are much bigger in the summer than in the winter. The temperatures measured in the asphalt carriageway on Podmežakla road section in January 2016 are shown in Figure 1. This road section is located in Alpine climate conditions in Gorenjska region. In winter, the temperature of asphalt is similar to the air temperature mostly, but during the summer period, asphalt temperatures are much higher than the air temperature.

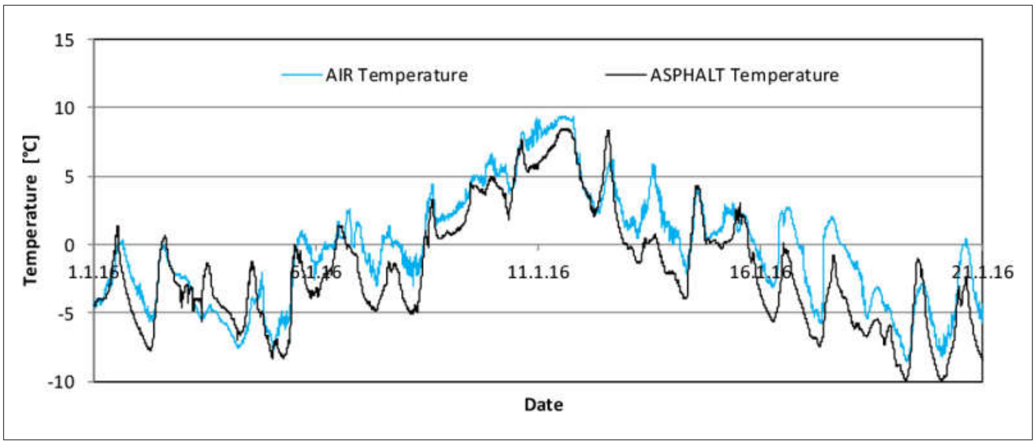

Figure 1 Measured air and asphalt temperatures on Podmežakla road section

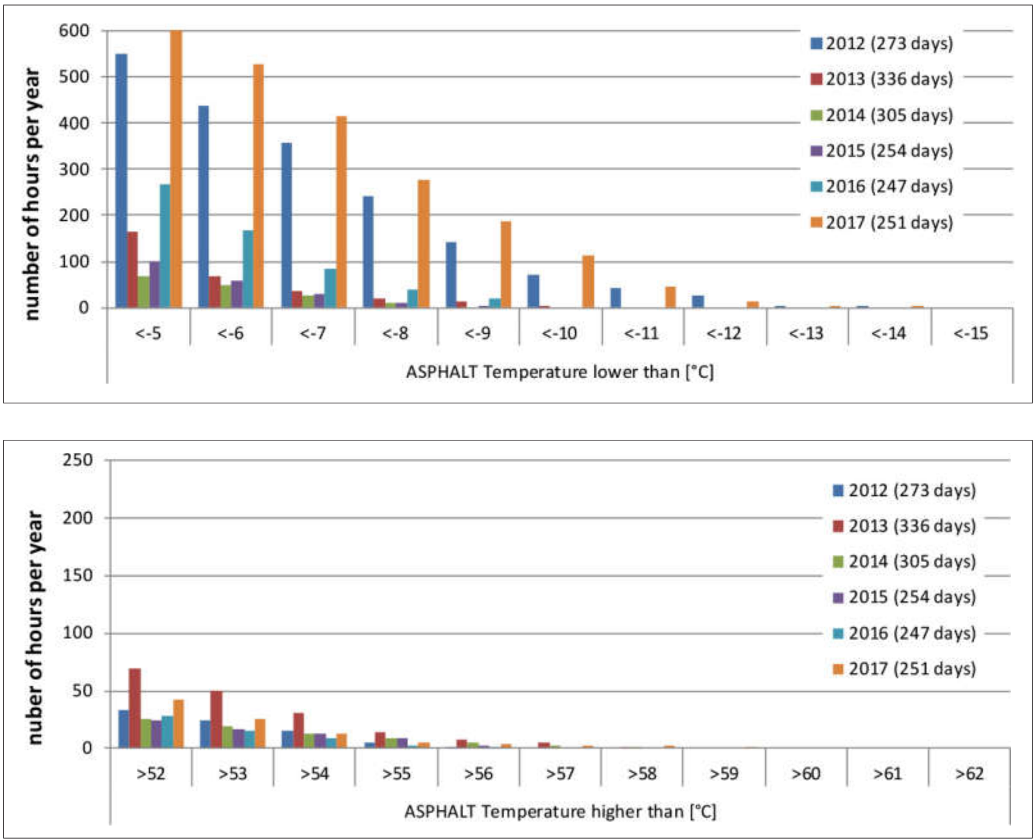

Figure 2 Measured time-scale of asphalt temperatures in 2012-2017 in the carriageway at the viaduct Podmežakla

The figure 2 shows the time period per year (in hours, not necessarily consecutive) of the highest and the lowest temperatures measured in asphalt on Podmežakla section. The appropriate bitumen should remain elastic up to at least -14 °C and also show no softening up to temperatures +58 °C. This gives a quite large temperature range of 72 °C.

3 Laboratory testing

On neat bitumen the usual scope of bitumen tests (R&B [1], Penetration [2], Fraass [3]) was performed as well as BBR [4], and DSR [5] tests. These bitumens have been laboratory aged with RTFOT [6] method and all tests were repeated on short term aged bitumens. In the last step the six bitumens have been laboratory aged with RTFOT and PAV [7] method and then re-tested. The procedures followed for BBR and DSR method are explained in more detail.

3.1 BBR test

The BBR test is aimed at determining the properties of long-term aged bitumens. For the aged bitumens B 70/100 (RTFOT + PAV), the BBR test was carried out according to standard at four temperatures -10 °C, -16 °C, -22 °C, -28 °C. As a result, at each test temperature was obtained:
- stiffness in the 60th second of loading designated S_{60},
- m-value, which expresses a change in stiffness during loading in the 60th second designated m_{60}.

The temperature/(stiffness after 60 seconds of loading S_{60}) graphs and the temperature/(m-value m_{60}) graphs were drawn. We assumed the linear response between the measured S_{60} and m_{60} at different temperatures.
In accordance with the US specifications AASHTO M 320 [8] temperature at S_{max} = 300 MPa and temperature at m = 0.300 were calculated. The temperature at the limit rigidity T_{S300} is defined as the temperature at which the rigidity of S_{60} is less than or equal 300 MPa. At stiffness greater than 300 MPa it is assumed that the thermal stresses accumulated in bitumen are excessive to allow for elastic behaviour of bitumen. It is assumed that bitumen is resistant to cracking when its rigidity is less than or equal to 300 MPa.
The temperature at the limit value $T_{m0.3}$ is defined as the temperature at which the m-value is greater than or equal to 0.300. A higher value of m means that such bitumen has a good ability to relax accumulated thermal stresses.

3.2 DSR test

For the tested bitumens B 70/100, the DSR tests were carried out according to standard [5]. Bitumen is a natural material that is viscoelastic, its behaviour depends on temperature. The DSR test has introduced the 'complex shear modulus' designated by |G*|. It expresses the overall resistance of a sample to deformations during recurrent sealing. The phase angle (δ) is the shift between the largest forced shear stress and the maximum shear deformation. During the investigation, the time delay in seconds is converted to the phase angle with respect to the oscillatory frequency. The phase angle can take values from 90° to 0°. In case the material is completely elastic, the phase angle is 0°, and the entirely viscous material has a phase angle of 90°. By increasing the temperature, the shear modulus decreases, and the phase angle increases.
Oscillatory shear tests were performed on long-term aged bitumens at four temperatures of 15 °C, 20 °C, 25 °C and 30 °C. We used a plate of 8 mm diameter and a sample height of 2 mm. From the measurements of the complex shear modulus and the phase angle B 70/100 at temperatures from 15 °C to 30 °C, behaviour at low temperatures can also be evaluated using the criterion given in AASHTO [8].

$$G^* \cdot \sin\delta \leq 5000 \text{ kPa} \left(\text{for RTFOT} + \text{PAV aged bitumen}\right) \quad (1)$$

On the graph we have drawn the measured values |G*|.sinδ at different temperatures. We assumed the linear response between the temperatures. We calculated the temperature at 5000 kPa to obtain $T_{G^*.\sin\delta=5MPa}$ for long-term aged bitumen.

3.3 Results

The results are presented in tables 1, 2 and 3 and on Figure 3 and Figure 4. After asphalt production (or RTFOT aging) the $T_{R\&B}$ is higher than 50 °C for all samples. R&B test also shows that samples number 1 and 5 stay softer than samples number 2, 3 and 6. The samples 1, 2 and 4 have the lowest T_{Fraass} after RTFOT. From penetration test we cannot draw any relevant conclusions.

After RTFOT+PAV aging the $T_{R\&B}$ is higher than 56 °C for all samples. R&B test also shows that samples number 1 and 5 stay significantly softer than samples number 2 and 3. The samples 1, 2 and 4 have the lowest T_{Fraass} after RTFOT+PAV. From penetration test we cannot draw any relevant conclusions.

Table 1 Results on neat (original) bitumen B 70/100

Sample No.	Penetration [mm/10]	$T_{R\&B}$ [°C]	T_{Fraass}[°C]	T_{S300}[°C]	$T_{m0.3}$[°C]
1	84	45.8	-13	-19.3	-21.9
2	77	47.4	-14	-21.9	-24.5
3	78	46.4	-13	-20.9	-23.2
4	70	48.2	-16	-21.5	-23.4
5	79	45.8	-10	-17.3	-20.7
6	81	46.4	-10	-20.2	-23.7

Table 2 Results on RFTOT aged bitumen B 70/100

Sample No.	Penetration [mm/10]	$T_{R\&B}$ [°C]	T_{Fraass}[°C]	T_{S300}[°C]	$T_{m0.3}$[°C]
1	51	50.8	-13	-18.8	-20.2
2	44	58.2	-14	-20.9	-20.6
3	39	56.8	-11	-20.4	-20.5
4	47	54.8	-14	-21.5	-23.4
5	50	51.4	-9	-14.9	-16.8
6	45	52.8	-10	-19.1	-21.8

Table 3 Results on RFTOT+PAV aged bitumen B 70/100

Sample No.	Penetration [mm/10]	$T_{R\&B}$ [°C]	T_{Fraass}[°C]	T_{S300}[°C]	$T_{m0.3}$[°C]	$T_{G^*.\sin\delta=5MPa}$ [°C]
1	30	59.2	-9	-17.0	-16.8	22.7
2	27	70.8	-9	-19.8	-12.5	21.8
3	22	70.6	-3	-18.0	-9.0	25.6
4	29	63.6	-10	-18.3	-13.3	20.9
5	29	56.4	-8	-14.4	-15.5	23.1
6	23	63.6	-2	-16.6	-16.0	24.7

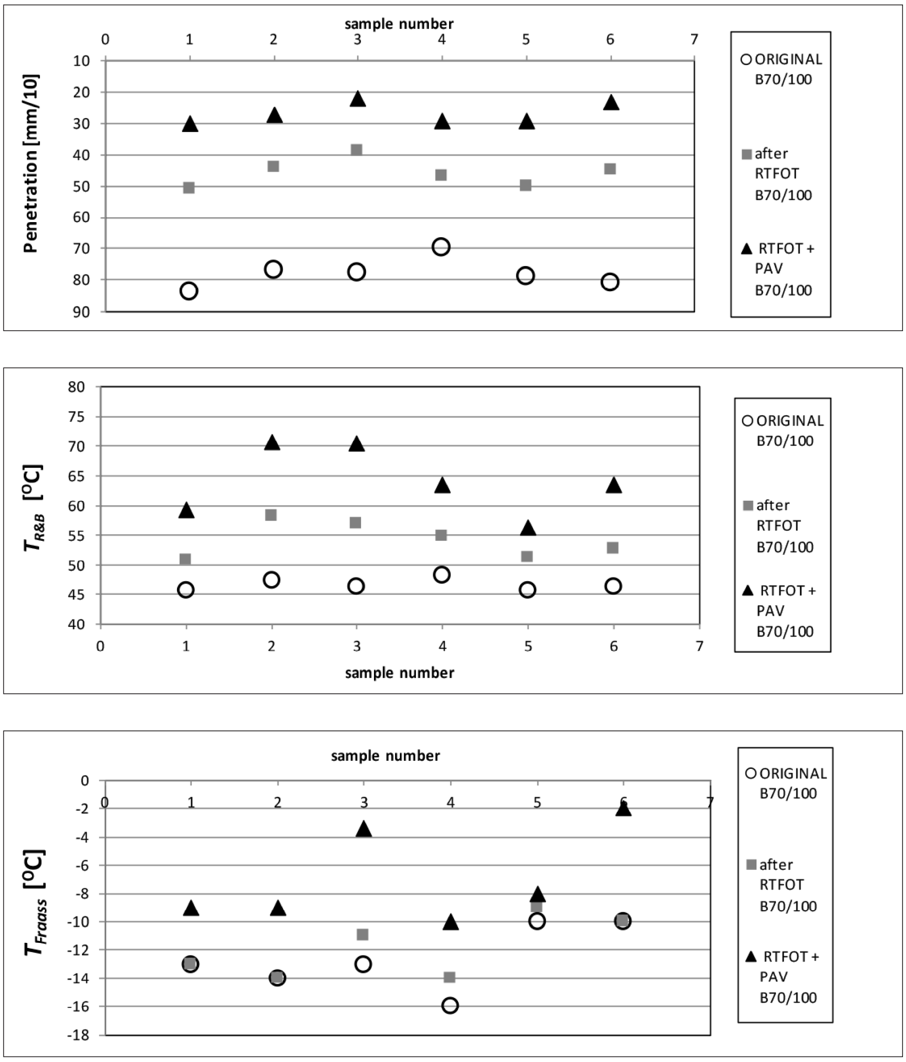

Figure 3 Change of penetration, $T_{R\&B}$ and T_{Fraass} after RTFOT and RTFOR+PAV aging

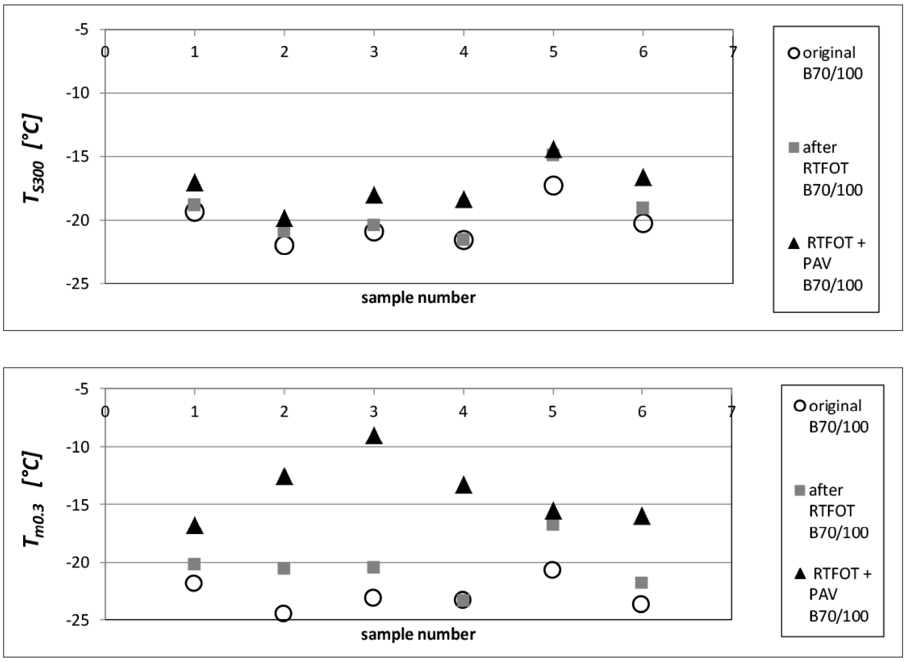

Figure 4 Change of T_{S300} and $T_{m0.3}$ after RTFOT and RTFOR+PAV aging

The BBR (Table 3 and Figure 4) and DSR tests (Table 3) can provide good insight into fatigue and low temperature behaviour after ageing. From BBR tests we can conclude that the samples number 1 and 6 have good resistance to fatigue and to low temperatures after aging, compared to other tested samples. On the other hand sample number 3 does not reveal good characteristics after long term laboratory aging (RTFOR+PAV). From the DRS tests we can conclude that samples number 3 and 6 have less desirable characteristics. Since these two tests (DSR and BBR) are not described in EN standards in all relevant details, the effort shall be done to improve reproducibility of BBR and DSR methods.
Some correlations between low temperature properties of bitumen have been defined [9, 10]. Our research has shown that for original, short-term aged (RTFOT) and long-term aged (RTFOT+PAV) bitumens B 70/100 it was not possible to establish reliable correlations between the T_{Fraass} ramp and the results of the BBR test – the temperature limit at 300 MPa T_{S300} or the temperature limit at the value m = 0,300 $T_{m0.3}$.
The best correlation (R^2 = 0.86) was found in the DSR test between T_{Fraass} and the threshold value with respect to the fatigue criterion $T_{G^*.\sin\delta=5MPa}$ for long-term aged bitumens B 70/100 as shown in Figure 5.

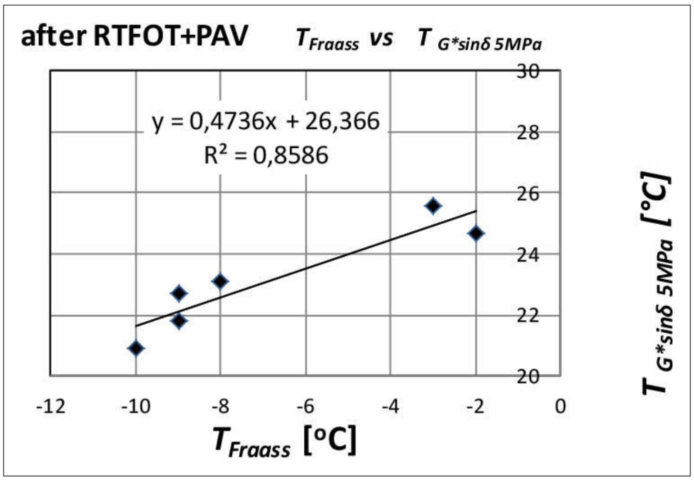

Figure 5 Correlations between T_{Fraass} in $T_{G^*\sin\delta=5MPa}$ for RTFOT+PAV aged pen grade bitumen B 70/100

4 Conclusions

In the present study an attempt was made to determine sensitivity to laboratory ageing for six different B 70/100 bitumens, and to find any correlations between the limiting temperatures obtained by the BBR test ($T_{m0.3}$ and T_{S300}), DSR results and the Fraass breaking point (T_{Fraass}). Six samples of original, short term and long term aged B 70/100 bitumen were extensively tested. It was found that short term ageing (RTFOT) has only a moderate effect on the low temperature properties of these samples. Long term ageing (RTFOT+PAV) has a significant effect on $T_{m0.3}$ and a somewhat smaller effect on T_{Fraass}. The least affected by long term ageing was T_{S300}. The found correlations between results of low temperature tests were mainly poor. For original, short-term aged (RTFOT) and long-term aged (RTFOT+PAV) bitumens B 70/100 it was not possible to establish reliable correlations between the T_{Fraass} ramp and the results of the BBR test – the temperature limit at 300 MPa T_{S300} or the temperature limit at the value m = 0,300 $T_{m0.3}$. The best correlation (R^2 = 0.86) was found in the DSR test between T_{Fraass} and the threshold value with respect to the fatigue criterion $T_{G^*.\sin\delta=5MPa}$ for long-term aged bitumens B 70/100.

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