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Performance Based Bitumen Testing Methods in Austria

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ABSTRACT

In the conventional bitumen testing scheme, the bitumen samples are examined by means of various tests (e.g. penetration, softening point with ring and ball, breaking point according to Fraass), which do not give any direct physical parameters of the bitumen or the asphalt produced with it for certain damage cases (e.g. cracks, rutting). A conclusion from these test values to the actual behaviour of the bitumen in the asphalt road is only possible through practical experience and estimation. Basically, three groups of properties have been defined for bitumen, which summarise the most important application-oriented properties: high-temperature properties (deformation behaviour), cold properties and ageing (short and long term ageing). In addition to the classical (empirical) methods, the following methods, so-called performance based requirements (germ. **GVO** = **G**ebrauchs**v**erhaltens**o**rientiert) methods, are used in Austria for testing bitumen in accordance with EU standards.

Keywords: Bitumen & Tar; Cracks & Cracking; Creep; Testing, Apparatus & Methods; Viscosity

INTRODUCTION

In contrast to the conventional (empirical) testing methods, the GVO-methods should test the bitumen as realistically as possible. They were developed within the framework of the US-American Strategic Highway Research Program (SHRP) under the name SUPERPAVE (SUperior PERforming Asphalt PAVEments). Performance based bitumen testing methods are (Hospodka, 2013):

Rolling Thin Film Oven Test (RTFOT) (EN 12607-1) (ASI, 2014)
Pressure Aging Vessel (PAV) to EN 14769 (ASI, 2012a)
Dynamic shear rheometer (DSR) to EN 14770 (ASI, 2012b)
Bending Beam Rheometer (BBR) to EN 14771 (ASI, 2012c)
Multiple Stress Creep and Recovery Test (MSCR) to EN 16659 (ASI, 2016)
Direct Tension Test (DTT) to AASHTO T 314-12 (AASCHTO, 2022)
Asphalt Binder Cracking Device (ABCD) to AASTHO PP 42-02 (AASCHTO, 2005)

PERFORMANCE BASED BITUMEN TESTING METHODS

Rolling Thin Film Oven Test (RTFOT) to European standard EN 12607

The short-term ageing of the bitumen is simulated with the RTFOT. Eight glasses are filled with 35 g of bitumen each. These glasses are then inserted horizontally into the holder (Figure 1 left). The test takes 75 minutes and is carried out at +163 °C. During these 75 minutes the glasses (Figure 1 bottom right) rotate at a speed of 15 rpm and hot air (4 litres/min) is constantly blown into the glasses through a lance (Figure 1 top right). This process is intended to simulate ageing during the mixing, transport and installation processes (Hospodka, 2013).

Figure 1. Apparatus for RTFOT: Rolling Thin Film Oven, top right: Air lance and vertical rotating drum, lower right: RTFOT bottles

In addition to the ageing process itself, the loss in mass of the sample can also be determined with RTFOT. After the test has been carried out and the RTFOT bottles have cooled down, the loss of mass is weighed or determined. The RTFOT test does not give us the same results as the other bitumen tests but provides us with a bitumen that has been aged in the laboratory for a short time for further test methods such as BBR, MSCR etc.

Pressure Aging Vessel (PAV) to European standard EN 14769

The PAV apparatus consists of a heatable pressure vessel, ten sheet metal trays and a tray holder (Figure 2) (Hospodka, 2013). The ageing of the bitumen by means of PAV is intended to provide evidence of the changes in the bitumen during a lying period of approx. 10 years.

Figure 2. The apparatus for the PAV test: left: Pressure Aging Vessel, centre: Pressure vessel, right: Bowl holder with filled bowls

First, the bitumen, which has been aged using RTFOT tests, is filled into ten metal trays approx. 3 mm thick, 50 g per tray. The shells are then placed in the shell holder and the shell holder is then placed in the pressure vessel preheated to +110 °C. After closing the lid, the pressure vessel is pressurised with 20.7 bar (300 PSI). When the temperature inside the pressure vessel has reached ±2 °C, the ageing process starts for 20 hours. After these 20 hours, the pressure in the boiler is slowly released for 8 - 10 minutes and then the sheet metal trays are placed in a drying oven at a temperature of +163 °C for another 30 minutes. Finally, the bitumen is emptied into tins. Bitumen conditioning with the PAV (as well as with RTFOT) does not give us results like the other bitumen tests but provides us with a bitumen that has been aged in the laboratory for further test methods such as BBR, MSCR, etc.

Dynamic Shear Rheometer (DSR) to European standard EN 14770

According to this Austrian standard, the asphalt mastic (mixture of bitumen and filler) is tested using DSR equipment (Figure 3). A known oscillating shear stress (shearing stress) caused by the oscillating movement is applied to the test geometry in which the bituminous test specimen is located. The lower plate on which the test specimen is located is stationary and the upper plate rotates alternately to the left and right (Figure 3, Figure 4) (Hospodka, 2013). This shear stress causes a deformation of the test specimen.

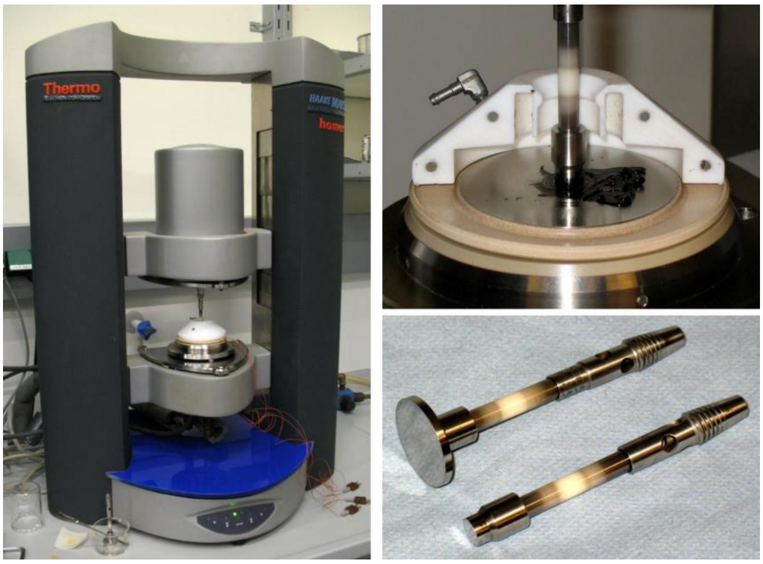

Figure 3. Dynamic shear rheometer (DSR) including plate-plate measuring system and measuring heads PP08 (Ø 8 mm) and PP25 (Ø 25 mm)

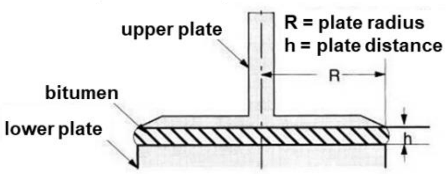

Figure 4. Plate-plate measuring system

Fatigue of the material ultimately leads to failure of the test specimen or to cohesion fracture in the installed predetermined breaking point (Figure 5) (Hospodka & Mandahus, 2017).

Figure 5. Clear cohesive fracture in the installed predetermined breaking point (specimen geometry with necking)

In the DSR test, shear modulus IG*I and phase angle δ are measured at temperatures +20 °C to +82 °C and shown on the following diagram (Figure 6) (Hospodka & Mandahus, 2017).

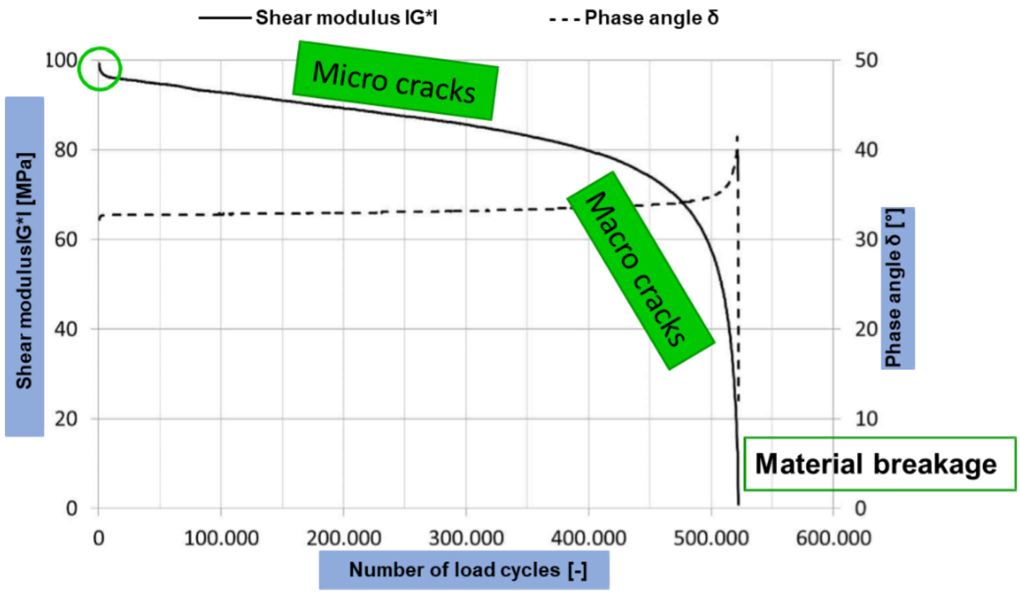

Figure 6. Fatigue diagram from the transient phase to failure of the test specimen

The shear modulus IG*I is the stress expressed in Pascal [Pa] that is necessary to achieve a certain deformation or that occurs at a given deformation. A phase shift angle δ of 0° corresponds to ideal elastic (e.g. rubber band), a phase shift angle of 90° to ideal viscous (e.g. plasticine) behaviour. In between there is the viscoelastic range relevant for bitumen.

Diagrams in Figure 7 and Figure 8 (Kammerer, 2017) show the comparison of the following three bitumen types after the DSR test: Road bitumen B 70/10, PmB 45/80-65 and PmB HiM (High Modified Binders). The bitumen industry contributes to the continuous development of products such as PmB HiM. The basis for polymer modified bitumen (PmB) in Austria is the European Standard EN 14023 (ASI, 2013), which is a matrix standard (framework). However, each European country can choose a different property (class) for a PmB bitumen with an identical product name. According to this EN 14023, it is therefore possible to describe a higher modification by increasing the requirements for the ring and ball softening point according to standard EN 1427 (ASI, 2007).

In Poland the product "PmB 45/80-80" has been included in the national implementation standard for the description of PmB HiM. For this purpose, the softening point requirement is class 2 with at least +80 °C. In the high temperature range (from +60 °C) the complex shear modulus of bitumen 70/100 according to RTFOT is significantly lower than that of modified bitumen and therefore a PmB has better resistance to permanent deformation (e.g.: wheel tracking) (Figure 7) (Kammerer, 2017).

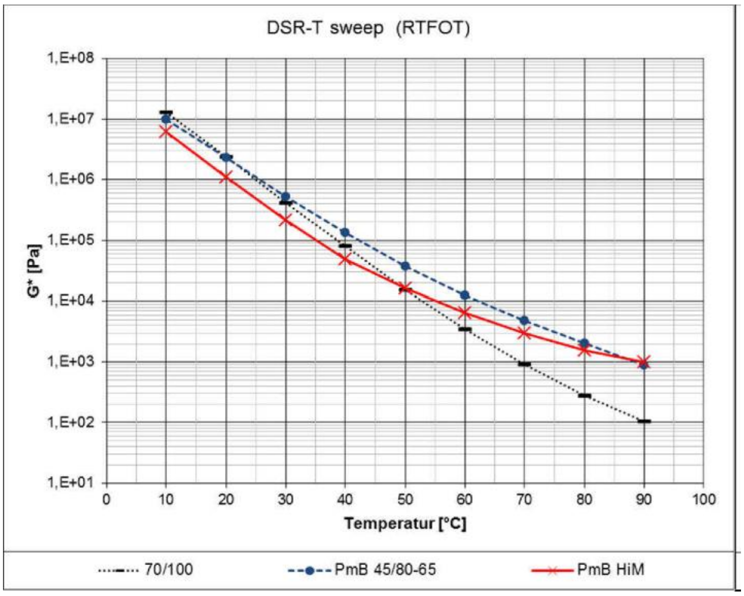

Figure 7. Comparative presentation of the results of complex shear modulus using the DSR test

The phase angle of bitumen 70/100 (according to RTFOT) increases continuously. The road bitumen behaves rather viscous. With PmB HiM (according to RTFOT), the phase angle decreases again from +40 °C (shows a more elastic behaviour) due to the High Modified (Figure 8) (Kammerer, 2017).

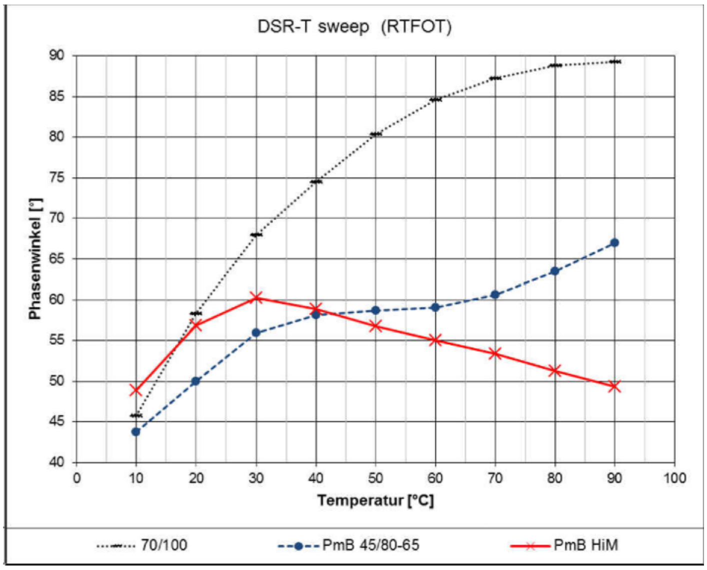

Figure 8. Comparative presentation of the results of phase angle using the DSR test

Bending Beam Rheometer (BBR) to European standard EN 14771

Thermal stress due to weathering is achieved by a cooling process starting at temperatures around 0 °C. Due to the low temperatures in winter, the building material asphalt, like most other materials, tries to shrink (contract) when cooling. However, since the asphalt is clamped in the road pavement, this shrinking process is therefore prevented and thus the thermal tensile stresses (cryogenic tensile stresses) are induced in the asphalt roadway structure. If this contraction is hindered in the asphalt and if these tensile stresses exceed the tensile strength of the asphalt, then cold cracks will be created in the asphalt (Figure 9) (Hrapović, 2022).

Figure 9. Cracks in asphalt as a result of low temperature

The low-temperature behaviour of bitumen can be determined using BBR (Figure 10, Figure 11) (Hospodka, 2023). For this purpose, a bitumen bar is centrally loaded with a constant load. The resulting deflection is recorded over time. The stiffness S(t) (Figure 12) (Hospodka, 2013) is calculated from the bending stress and deformation after a loading time of 60 seconds. According to the standard specifications, the temperature at stiffness is given as 300 MPa.

Figure 10. Bending Beam Rheometer (BBR)

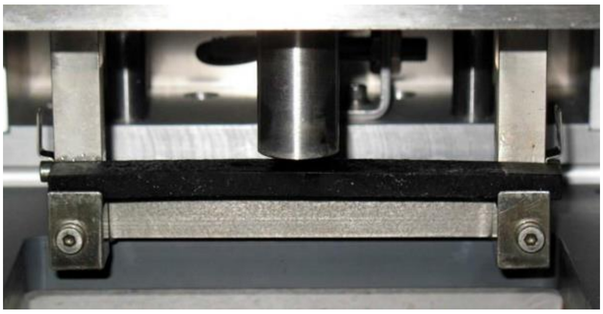

Figure 11. BBR test arrangement - bitumen beam

At low temperatures, tensile stresses are created due to shrinkage (product contracts). The larger the creep stiffness at a low temperature, the more brittle the bitumen is and the more likely cold cracks in the asphalt structure are to occur (cryogenic tensile stresses). As a further characteristic, the "*m*-value" [–] (Figure 12) (Spiegl et al., 2008) is calculated as the logarithm of stiffness against the logarithm of time as the absolute value of the curve slope. The *m*-value describes the relaxation of the bitumen at low temperatures, the higher the better.

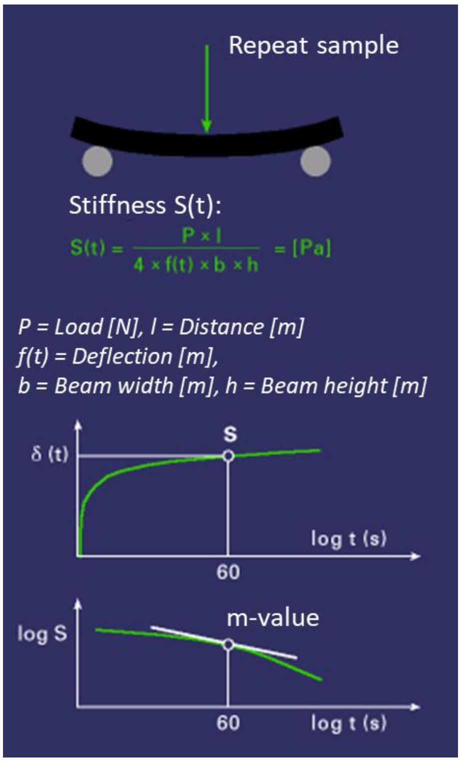

Figure 12. Bending Beam Rheometer (BBR): stiffness S(t), deflection δ(t) and *m*-value

The diagrams in Figure 13, Figure 14 (Kammerer, 2017) show the comparison of three bitumen types - road bitumen B 70/10, PmB 45/80-65 and PmB HiM ("High Modified") - using BBR according to RTFOT and PAV. The bitumen 70/100 (according to PAV) in Figure 13 has a significantly higher temperature at 300 MPa and is therefore more sensitive to the occurrence of cold cracks. The PmB HiM (according to PAV) has the lowest value at –26 °C and thus shows a high resistance to cryogenic tensile stresses (Figure 13, red line). The *m*-value (Figure 14) of bitumen 70/100 (according to PAV) is lowest at around –18 °C and highest for PmB HiM (according to PAV), thus clearly indicating the differences in the relaxation ability of the products (the higher the better the recovery).

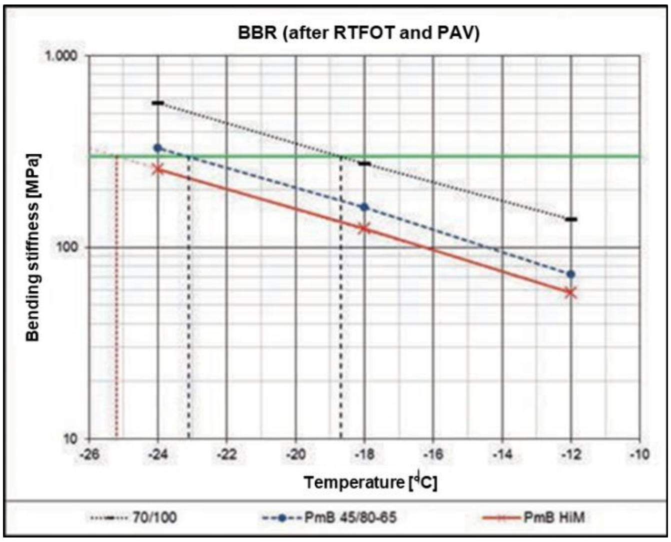

Figure 13. Bending (flexural) stiffness in [MPa] of the conventional road bitumen 70/100 and PmB 45/80-65 using BBR according to RTFOT and PAV

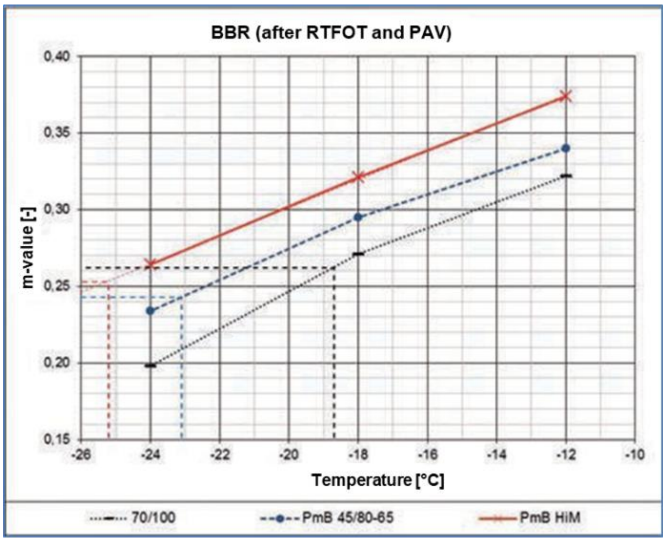

Figure 14. m-value [-] of the conventional road bitumen 70/100 and PmB 45/80-65 using BBR according to RTFOT and PAV

Multiple Stress Creep and Recovery Test (MSCR) to European standard EN 16659

The elastic properties of the bitumen are determined by applying a shear stress for one second and a nine-second load-free phase (reset). This test cycle is repeated 10 times at a predetermined stress level and temperature. From this, the recovery [% R] and resilience [Jnr] are calculated (Figure 15) (Kammerer, 2017).

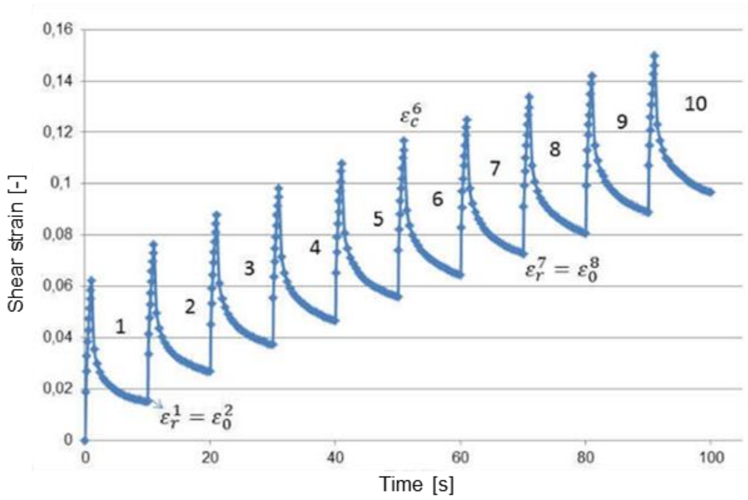

Figure 15. Typical creep recovery curve for ten consecutive cycles

Recovery [% R]

Recovery is the proportion of the elastic elongation of a specimen after a creep and recovery cycle. The resilience [Jnr] is the permanent strain after a load cycle in relation to the applied shear stress. The higher the recovery, the lower the permanent elongation (resilience) and the more elastic the product is, i.e. more resistant to permanent deformation (rutting in asphalt). The comparative presentation of the results using the Multiple Stress Creep and Recovery Test (MSCR) after short term ageing (RTFOT) in the laboratory for three types of bitumen - road bitumen B 70/10 (Figure 16) (Spiegl & Steidl, 2009), PmB 45/80-65 (Figure 17) (Vondenhof et al., 2013) and PmB HiM (highly modified binders "High Modified"), is shown in Figure 18, Figure 19 and Figure 20 (Kammerer, 2017).

Figure 16. Conventional road bitumen

Figure 17. Polymer modified bitumen (PmB)

The bitumen 70/100 (according to RTFOT) in Figure 18 shows no recovery - not modified. The modified bitumen grades, on the other hand, have very high levels of recovery. The PmB HiM with values above 90% is significantly higher than the PmB 45/80-65 (Figure 19, Figure 20). The permanent elongation is significantly higher for bitumen 70/100 (Figure 18) compared to the modified bitumen, although PmB HiM (Figure 20) also has a lower value than PmB 45/80-65 (Figure 19) and behaves much more elastically (Kammerer, 2017).

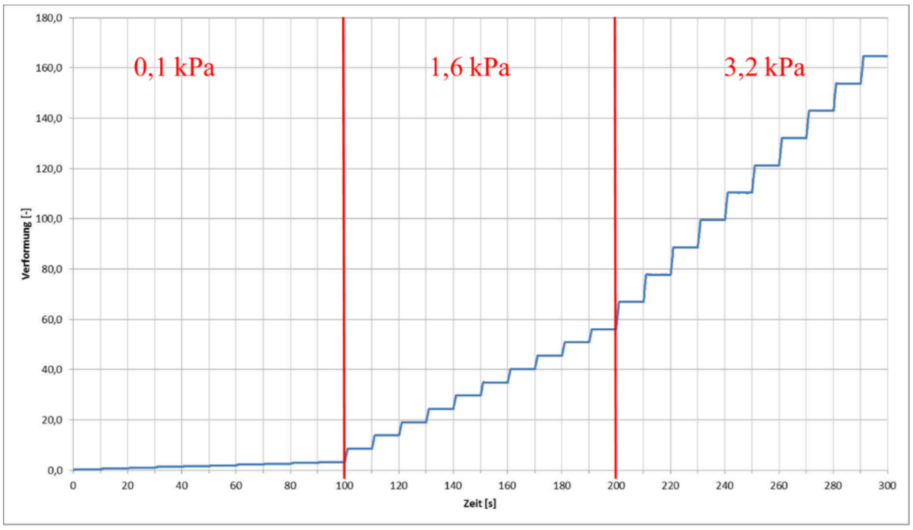

Figure 18. MSCRT of the conventional road bitumen B 70/100 according to RTFOT

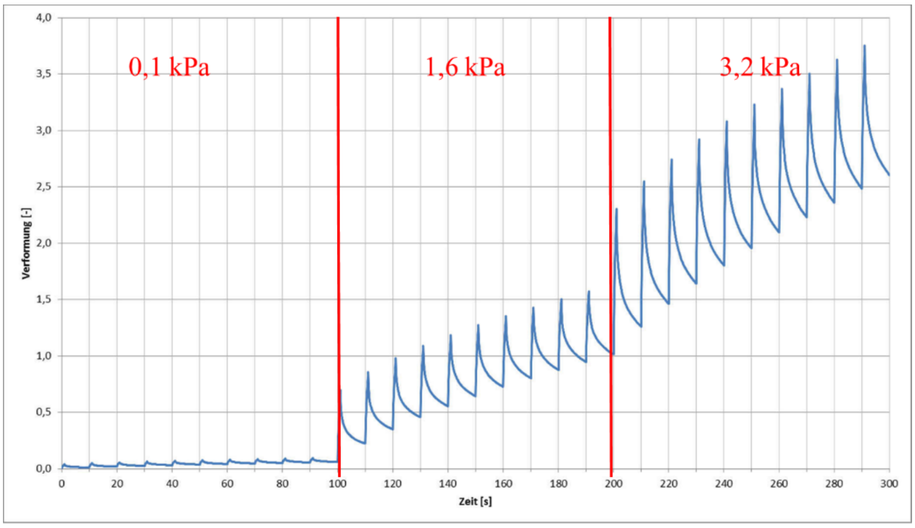

Figure 19. MSCRT of PmB 45/80-65 according to RTFOT

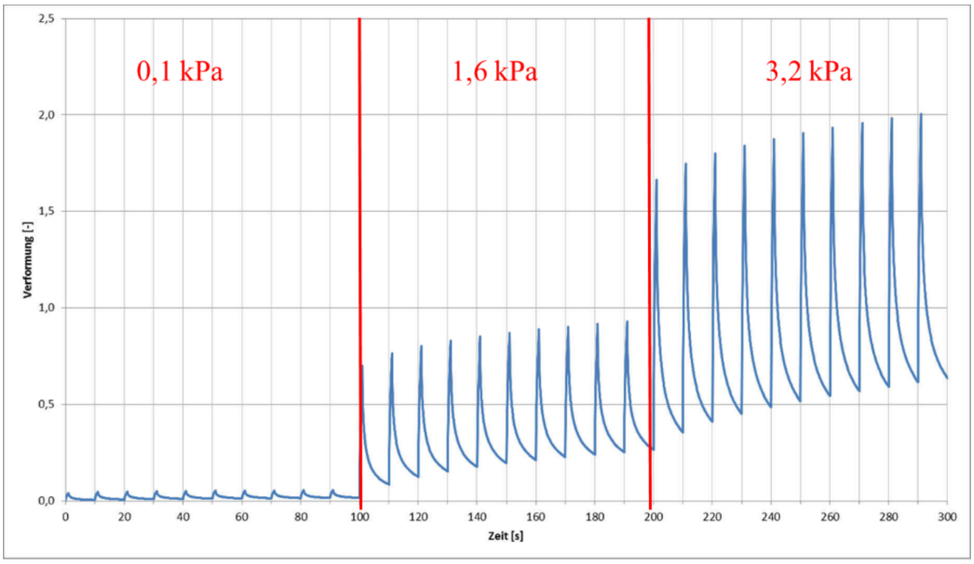

Figure 20. MSCRT of PmB HiM according to RTFOT

Direct Tension Test (DTT) to AASHTO T 314-12

The Direct Tension Test is a tensile test at low temperatures. Many studies show a strong correlation between stiffness and elongation at break of bitumen. With regard to the prevention of cold cracking, it is important that the bitumen can experience a certain minimum elongation before it cracks. Figure 21 (Maschauer, 2017) and Figure 22 (Pavement Interactive, 2024) shows the measurement principle. The results of the test, elongation at break and stress at break, are thus a measure of the low-temperature behaviour. If the elongation at break is large, the bitumen is considered ductile at low temperatures (Maschauer, 2017).

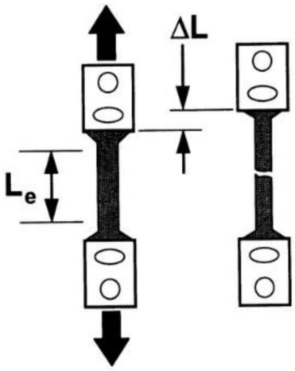

Figure 21. Measuring principle of the Direct Tension Test

Figure 22. Direct Tension Tester - Mounted sample

Asphalt Binder Cracking Device (ABCD) to AASTHO PP 42-02

This experiment is a relatively new method for assessing the low-temperature behaviour of bitumen. The core of the device are round silicone moulds (Figure 23) (FHWA, 2024), in which an inner metal ring with built-in measuring sensors is located. The ring is made of an iron-nickel alloy (Invar), which has a very low coefficient of thermal expansion. Asphalt binder is poured around the ring then cooled to very low temperatures in a controlled manner (Figure 23).

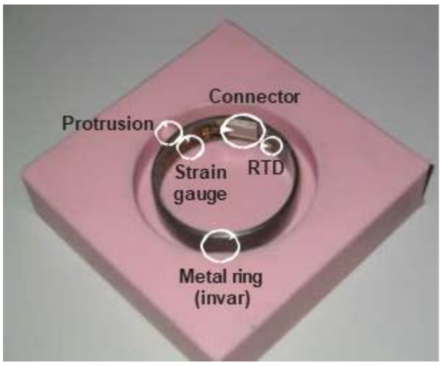

Figure 23. A ring of metal with very low thermal contraction is instrumented to measure temperature and strain

The bitumen is filled into the gap between the silicone and the invar ring. A photo of the set-up can be seen in Figure 24 (FHWA, 2014). The sample mould together with the poured bitumen is now cooled down in the cold chamber. The bitumen contracts more than the iron-nickel alloy due to the falling temperature and will crack when the breaking stress is reached. The result of the test is the breaking stress, the temperature associated with the breaking stress and the coefficient of thermal expansion, which is determined for the first time in a standard test. In addition, the test provides reliable statements about the influences of polymer-modified bitumen in the low-temperature range (Maschauer, 2017).

Figure 24. Asphalt Binder Cracking Device (ABCD) to AASTHO PP 42-02

CONCLUSIONS

Although only about five percent of the mass of our asphalt roads consists of bitumen (the rest is rock), the mechanical properties of asphalt are decisively influenced by the bituminous binder. Bitumens are low-volatile, dark-coloured mixtures of many substances, which, in addition to hydrocarbons and hydrocarbon derivatives, can also contain sulphur, oxygen and nitrogen. Bitumen is resistant to the effects of most inorganic acids, salts, aggressive waters, carbonic acid and alkalis. Road bitumen is produced by distillation and, if necessary, subsequent oxidation. Three test methods have been defined for the classification of bitumen types, which form the essential basis for the classification of bitumen types according to EN 12591 (ASI, 2009): Needle penetration according to EN 1426 (ASI, 2023), softening point ring and ball according to EN 1427 (ASI, 2007) and breaking point according to Fraass according to EN 12593 (ASI, 2015). In the conventional bitumen testing scheme, the bitumen samples are examined by means of various tests (e.g. penetration, softening point with ring and ball, breaking point according to Fraass), which do not give any direct physical parameters of the bitumen or the asphalt produced with it for certain damage cases (e.g. cracks, rutting). A conclusion from these test values to the actual behaviour of the bitumen in the asphalt road is only possible through practical experience and estimation.

Since conventional bitumen testing methods do not provide information on the actual material parameters such as stiffness or phase angle and the bitumen is not stressed as in reality (type of loading, climatic conditions, etc.), empirical (conventional) tests must be viewed critically. In addition to the classical (empirical) methods, the following methods, so-called performance based requirements (Germ. GVO = gebrauchsverhaltensorientiert) methods, are used in Austria for testing bitumen in accordance with EU standards. These GVO methods are much more practice-oriented and they give the statement about the material parameters like stiffness, phase angle, bitumen ageing, etc. The practical benefit of these "new" performance-oriented bitumen test methods is, on the one hand, the qualitatively better results of the individual tests. This makes it possible to optimise the asphalt mix formulation (bitumen + aggregate) using theoretical asphalt behaviour models, and thus to reduce the layer thicknesses of the road surface without sacrificing road service life in order to save material resources.

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