Viennese Aging Procedure – Behavior of various bitumen provenances

Daniel Maschauer[1], Daniel Steiner[1], Johannes Mirwald[2], Bernhard Hofko[1] and Hinrich Grothe[2]

[1]Vienna University of Technology, Institute of Transportation
Research Center of Road Engineering,
Gusshausstraße 28/230-3, 1040 Vienna, Austria,
Tel: 0043 1 58801 23360,
Email: daniel.maschauer@tuwien.ac.at

[2]Vienna University of Technology, Institute of Materials Chemistry
Getreidemarkt 9/BC/01, Vienna 1060, Austria

Abstract Bitumen changes its properties in the course of time under natural and anthropogenic influences due to its organic origin. These processes are commonly called "aging". The material becomes stiffer and more brittle, resulting in less favorable low temperature and fatigue behavior. For this reason, it is important to simulate the aging of the material in the laboratory in an accelerated way to study the change in material behavior and minimize damage on the road. On the bitumen level, the standardized methods RTFOT (Rolling Thin Film Oven Test) and PAV (Pressure Aging Vessel) are used. Various methods have been developed in the past to simulate aging of asphalt mixes or compacted specimens. The study presented in this paper evaluated the aging method "Viennese Aging Procedure" (VAPro) for applicability with the aid of a parameter study with bitumen of different origin. VAPro uses realistic boundary conditions (temperature: +60°C, pressure: ~ 0.3 bar) and increases the rate of aging of the compacted asphalt mix specimen by perfusing (1.0 l/min) with ozone and nitric oxides enriched air for three days. The state of aging of the extracted bitumen is assessed using the Dynamic Shear Rheometer (DSR). Significant differences between the employed bitumen are determined, which is probably caused by their different initial stiffness and their origin. The stiffness after VAPro of the extracted bitumen is between 1.2 and 2.6 times the RTFOT+PAV-aged state.

Keywords VAPro, Ozone, NO_x, Long Term Aging, Hot Mix Asphalt, Stiffness, DSR

1 Introduction

Organic materials, such as bituminous binders, change their properties over time due to natural and anthropogenic influences. Aging of bitumen and asphalt mixtures is divided in short-term aging (STA) during production and paving and long-term aging (LTA) during its service life on the road. STA is caused by fast chemical oxidation due to high temperatures and a high specific surface contacting with oxidant agents at mix production, as well as the vaporization of remaining volatile components (Baek et al, 2012). LTA is characterized by slow oxidation primarily in the upper layers of the asphalt by oxidant gases available in the atmosphere like ozone or nitric oxides (Morian et al, 2011). Due to aging, the bitumen becomes brittle and hard, which leads to a deterioration in the performance properties of asphalt pavements, especially, resulting in more likely low-temperature cracks and decreasing fatigue resistance (Teshale et al, 2011); (Hofko et al, 2014).

For this reason, it is important to accelerate the aging of the material in the laboratory in order to investigate the change in material behavior, as an input in mix design optimization, to minimize damage on the road by optimized pavements that are more durable. On bitumen level, the standardized methods RTFOT (Rolling Thin Film Oven Test) for STA and PAV (Pressure Aging Vessel) for LTA are commonly used (da Costa et al, 2010). For aging, loose or compacted asphalt mixtures in laboratory more than 30 procedures have been developed over the last decades. Many of these procedures use high temperature (above +100°C) and/or high pressure that do not occur in the field (Bell et al, 1994). As a consequence, additional effects could be induced by these methods, such as evaporation of further volatile binder components that are not triggered in the field.

Therefore, a new procedure called ‘Viennese Aging Procedure’ (VAPro) was developed at Vienna University of Technology for aging compacted asphalt specimens under realistic boundary conditions concerning temperature and pressure (VAPro) (Steiner et al, 2016). The main objective of this paper is to test the applicability of VAPro. For this purpose, asphalt mixes with the same aggregate composition but with bitumen of different origins were examined and evaluated using the Dynamic Shear Rheometer on extracted binders after VAPro aging. The results show that the VAPro is easily applied and the aging level of the extracted bitumen is between 1.2 and 2.6 times the RTFOT+PAV-aged state. Moreover, it is evident that the origin of the bitumen has large impact on the achieved level of aging.

2 Materials and Methods

The study uses an asphalt concrete with a maximum grain size of 11 mm (AC 11). The coarse aggregates used for the mix is a porphyrite and the filler is powdered

limestone. Six mixes were produced, four with paving grade bitumen (70/100) of different origins and two with polymer-modified bitumen (PmB 45/80-65) from the same source but different production years. Table 1 gives a list of the used bitumen. The bitumen content is set to 5.2% by mass for each mix with a target void content of 8% by volume.

Table 1 Bitumen types used

Bitumen Type	Origin	Penetration in 1/10mm	Dynamic Shear Modulus @ 1.59Hz, 64°C in MPa
70/100	A	88	1.34
70/100	B	79	1.09
70/100	C	64	1.77
70/100	D	55	1.57
PmB 45/80-65	A (2012)	67	5.58
PmB 45/80-65	A (2017)	65	4.97

For preparation of the mixes, a laboratory mixer, according to EN 12697-35 is used. The mixing temperatures are set at +170°C for the paving grade bitumen and +185°C for the polymer-modified bitumen, respectively. Subsequently, asphalt slabs (50x26x4 cm) are compacted in a roller compactor according to EN 12697-33. From these slabs, the specimens (eight per slab) with a diameter of 100 mm are cored. The air void content of the produced slabs ranges from 4.8 to 9.2% by volume. For each mix, three specimens with an air void content of about 7 % by volume were selected for aging with VAPro.

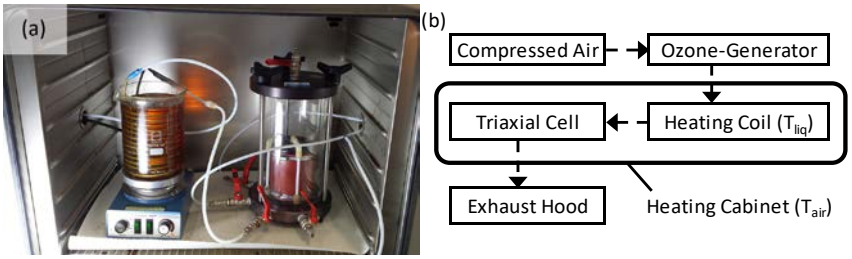

Fig. 1 VAPro setup: (a) Photo and (b) Schematic Diagram of the setup

Fig. 1 shows the setup that is used for VAPro. Compressed air from the laboratory system is directed through the ozone generator. The generator enriches the compressed air with ozone and nitric oxides using a dielectric barrier discharge tube. A flow regulator ensures a constant flowrate of 0.9 – 1.1 l/min. The gas mixture is then heated to +70°C (T_{liq}) via a heating coil, which is placed in a beaker glass filled with vegetable oil that is placed on a heatable magnetic stirrer. The specimen is mounted within a triaxial cell between two filter stones and is covered with an elastic membrane. The oxidant flows through the samples from bottom to

top. An overpressure of about 80 kPa in the triaxial cell ensures that the membrane is pressed against the specimen so that the gas must flow through the specimen. The triaxial cell and the heating coil device are housed in a heating cabinet at an air temperature of +60°C (T_{air}). The duration of aging for one specimen is set to three days since former studies, e.g. (Steiner et al, 2016) found that this duration gives an aging state of the recovered binder that resembles that of an RTFOT+PAV aged bitumen.

After aging, the bitumen is extracted with tetrachloroethylene as solvent according to EN 12697-3. The solvent is then separated from the bitumen by vacuum distillation according to EN 12697-3. Dynamic Shear Rheometer (DSR) tests are performed on the bitumen obtained from the VAPro-aged specimens. The DSR-tests are also carried out on the virgin bitumen samples, extracted bitumen samples of slab remnants after drilling (short-term aging condition), RTFOT samples and RTFOT+PAV samples for comparison. The test are carried out at temperatures ranging from -40°C to +82°C in 6° steps. The test frequencies are 0.1, 0.3, 1.0, 1.59, 3.0, 5.0 and 10.0 Hz.

3 Results and Discussion

For investigation of the level of aging, the changes in behavior due to VAPro-aging are analyzed. For comparison, the slab remnants, RTFOT and RTFOT+PAV samples are also examined. Fig. 2 shows the relative change in dynamic shear modulus. The results presented are for a frequency of 1.59 Hz at 64°C. Similar trends can be observed for other frequencies and temperatures.

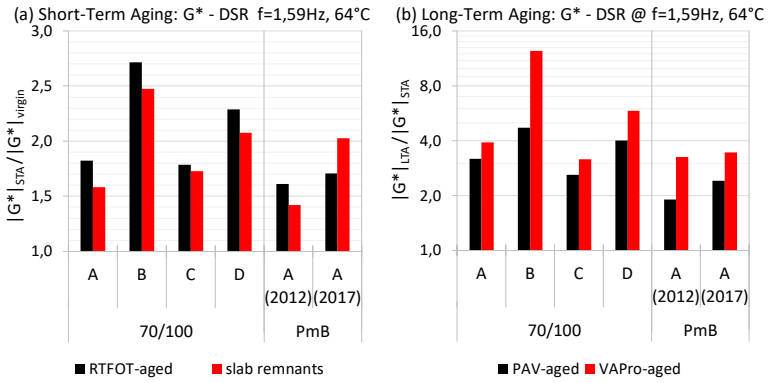

Fig. 2 Dynamic Shear Modulus G*: (a) Comparison of STA (ratio of STA condition to virgin condition) (b) Comparison of LTA (ratio of LTA condition to STA condition)

For STA, it can seen that the achieved level of aging of the slab remnants resembles to that of the RTFOT-samples. The level of aging ranges from 1.5 to 2.5.

For each bitumen, with the exception of bitumen from source A(2017), the aging level of the slab remnants is slightly below RTFOT aging. It can be stated that the RTFOT process is a good representation of the aging processes during laboratory production. The differences between the bitumen of different origin can already be seen here: E.g. paving grade bitumen from source B is significantly more aging susceptibly (factor 2.5) than all other paving grade samples.

For LTA, the tendency of the differences is similar. For the paving grade bitumen, the level of aging due to VAPro ranges from 3 to 13. The achieved level of aging corresponds with the dynamic shear modulus of the virgin bitumen. The bitumen with the smallest increase has the biggest virgin shear modulus and vice versa (cf. Table 1). For both polymer-modified bitumen, the achieved level of aging is quite the same, which indicates the constant quality of the supplier. The PAV-aged samples are below the VAPro-samples. A significant difference between PAV and VAPro shows the bitumen from source B. This gives a hint that probably the PAV-procedure does not represent the real aging processes quite well for every bitumen from any source.

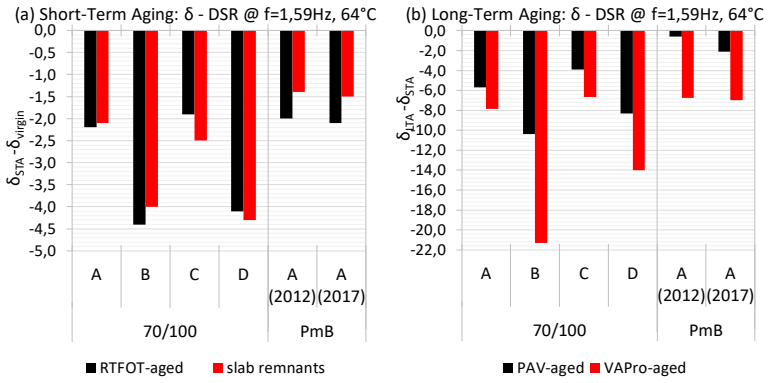

Fig. 3 Phase Lag δ: (a) Comparison of STA (difference of phase lag of STA minus phase lag in virgin condition) (b) Comparison of LTA (difference of phase lag of LTA minus phase lag of STA)

Fig. 3 shows the changes in phase lag. Similar observations in behavior can be made here. For short-time aging, RTFOT resembles to the slab remnants. For long-term aging the decrease of phase lag of the paving grade bitumen corresponds with the increase of dynamic shear modulus. The bigger the increase in shear modulus, the bigger the decrease in phase lag. The decrease of phase lag for the two polymer-modified bitumen due to VAPro is very similar. This again is a sign for the constant quality of the supplier. It should be noted that the PAV-samples of the polymer-modified bitumen show barely any decrease of the phase angle and the bitumen from source B has again the most significant difference between PAV and VAPro. This, once more indicates that the PAV-procedure might

not be the optimal method to represent real aging processes depending on the bitumen source.

4 Conclusion

The tests carried out in this paper show that the Viennese Aging Procedure (VAPro) is well applicable on a broad basis. VAPro simulates aging processes by perfusing cylindrical specimens with ozone and nitric oxide enriched air with realistic boundary conditions concerning temperature and pressure (+60°C, ~0.3 bar).

Stiffness and embrittlement of paving grade bitumen from different sources as well as two polymer-modified bitumen from the same source but different production years were investigated using the Dynamic Shear Rheometer (DSR). There are clear differences in the results of the individual bitumen, which indicates that the origin of the bitumen has an influence on aging behavior. The level of aging of some VAPro-samples differs significantly from the RTFOT+PAV-samples, which suggests that the PAV method does not capture the entire aging processes that occur in the field. Additional results of cyclic indirect tensile test, which are not included in this paper, are available for future discussion.

To investigate the low-temperature behavior of VAPro-aged specimens, the device will be developed further to age prismatic specimens for TSRST and UTST.

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