AGING OF BITUMINOUS BINDERS

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Abstract

Bituminous binder in asphalt mixture is exposed to the influence of aging, which is intensified during mixing and paving, as high temperature strongly accelerates the aging of bituminous binders. The aging of the binder is generally divided into short-term and long-term aging. The work focuses on comparing the properties of bitumen binders that differ in penetration value and aging level. All binders in the study are divided into these aging categories, and their properties are compared with the properties of unaged binders. The comparison of properties is carried out using basic empirical tests (penetration and softening point) as well as rheological tests (complex shear modulus and phase angle).

Keywords

Bitumen, aged binders, phase angle, complex shear modulus, dynamic shear rheometer

1 INTRODUCTION

Bitumen is the most common binder used in road construction, primarily for its good viscoelastic properties and its ability to withstand traffic load.

In Europe, bituminous binders are classified into several categories based on their penetration depth as measured by a penetration test using a needle. With increasing penetration values, the bitumen becomes softer. Generally, in countries with lower average annual temperatures, softer bituminous binders are used, while in regions with higher average temperatures, harder binders with lower penetration values are employed. Aging affects several fundamental properties of bitumen binders, including rheological properties such as viscosity, stiffness, and elasticity. Aged binders tend to have higher stiffness and may become brittle, which can lead to cracks in the road surface [1], [2].

This article provides a brief description of the aging process of bituminous binders, its impact on their properties and functions, and the resulting effect on road surfaces. The article also offers a description of the methods and materials used, considering the existing theory on the aging of bituminous binders.

The study compares the results of the rheological properties of bituminous binders, whether for paving grade bitumen or modified bitumen, before and after exposure to various aging tests. These results were obtained using a dynamic shear rheometer, short-term aging tests (RTFOT), and long-term aging tests (PAV). The aim of the work is to specify the properties of bituminous binders, particularly their changes over their lifespan. The study also assessed the impact of using polymer-modified binders, such as type RC (suitable for asphalt mixtures with a higher content of reclaimed asphalt), on their susceptibility to aging.

The term "aging of bituminous binders" refers to the chemical and physical changes that occur in bituminous binders over time due to various environmental factors and exposure to external influences. Bituminous binder is commonly used in pavement structures, and its aging can affect the properties and lifespan of the entire road [3].

The main factors influencing the degree of aging of bituminous binders include:

- Oxidation of the binder, leading to chemical processes and increased brittleness, which can result in cracks in road surfaces and reduced pavement life.
- Temperature fluctuations, especially extremely high temperatures, can accelerate the aging process of binders due to increased reactivity with oxygen and subsequent oxidation.
- UV radiation causes aging of binders by breaking down individual molecular structures, leading to changes in physical properties and potential binder bond disruption.
- Moisture, whether from the air or, more significantly, from rain, can cause asphalt mixtures and bituminous binders to absorb water, resulting in increased volume and softening of the binder. This can lead to reduced resistance to freezing and damage, especially in aged binders.
- Mechanical damage, such as repeated overloading by vehicles beyond the designed load limits, can also accelerate binder aging and cause cracks in the road surface [4].

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- Chemical damage most commonly occurs when salt is used for winter maintenance, but also when bituminous binders encounter other petroleum products, such as motor oil.

The aging process and its adverse effects can be mitigated or eliminated through various methods. These methods include regular road maintenance, the addition of various modifications and additives to binders during mixing and the consideration of binder aging in mixture design. Finally, regular surface inspections ensure the longevity of roads [5].

Various approaches to modified RC binders

The paper examines two different binders suitable for use in mixtures with reclaimed asphalt, known as RC binders. These are modified binders designed to ensure compatibility with aged binders in the mixture and the effective utilization of the properties of the old binder. The approach to the production and use of these binders varies significantly among different European countries. This work compares the Austrian and German approaches to RC binders.

In Germany, RC binders are softer and less modified due to the requirements of the ZTV Asphalt StB 07 regulation, which sets an upper limit on the softening point and by proxy restricts the use of a high content of modification additives. Therefore, softer binders are preferred, which, when mixed with recycled binders, should theoretically soften the resulting product, and extend its lifespan while enhancing its resistance to aging.

In Austria, the approach differs primarily in terms of the degree of modification. Since Austria does not have any upper limits on the softening point, a high level of modification can be added to mixtures with added reclaimed asphalt. While this increases the softening point of the resulting binder, making it stiffer, it also widens the range of applicability and, therefore, improves low-temperature properties [6].

2 METHODOLOGIES

The aging of bituminous binders is generally divided into short-term and long-term aging. Short-term aging primarily occurs during the production and laying of asphalt mixtures, while long-term aging occurs during the period of road use over its lifespan. In laboratories, these aging processes are usually simulated using Pressure Aging Vessel (PAV) tests for long-term aging and Rolling Thin-Film Oven Tests (RTFOT) for short-term aging. Both tests are crucial for evaluating the behaviour of bitumen binders over their lifespan and their use in mixtures, leading to better-informed decisions in pavement mixture design [7].

Subsequently, samples of various bituminous binders that were prepared in this manner were tested in a dynamic shear rheometer (DSR), and the values obtained for their complex shear modulus and phase angle were evaluated.

RTFOT (Rolling Thin-Film Oven) test

The RTFOT is one of several laboratory tests that can be used to simulate the aging of bituminous binders, specifically short-term aging. In this test, binder samples are exposed to a temperature of 163 °C while being rotated and agitated to closely replicate the behaviour of binders during mixing and compaction in the mixtures used for road pavements.

Individual binder samples weigh 35 ± 0.5 grams. They are poured into glass containers, which are rotated at a speed of 15 revolutions per minute for a duration of 75 minutes while hot air is continuously pumped into the containers at a rate of 4 litres per minute [8].

PAV (Pressure Aging Vessel) test

The PAV test is used to simulate the long-term aging of bituminous binders in a relatively short time. During the test, bituminous binder samples are placed in a pressure vessel, and a combination of high temperature and pressure is applied to the binders. This combination of factors accelerates the oxidation process and helps determine the behaviour of binders after several years in the road pavement.

Binders for the test are poured into dishes in 50 g portions, preheated to 100 °C. The filled dishes are then placed inside the pressure vessel, and aging simulation occurs for 20 hours under a pressure of 2.1 MPa at a temperature of 100 °C [9].

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Complex shear modulus (G*) and phase angle (δ) evaluation

To obtain these values, a dynamic shear rheometer was used. A dynamic shear rheometer is a common tool used to evaluate the rheological properties of materials, including bitumen. In practice, it is used to determine viscosity and assess the elastic properties of bitumen, which are essential for understanding the behaviour of binders at different temperatures and stress levels. One of the outputs of the testing is the phase angle, which provides information about the viscoelastic behaviour of the binder. The following section describes the testing process in the laboratory using a dynamic shear rheometer [10].

- Sample preparation begins by heating the bitumen to a temperature not exceeding 100 °C above its softening point and pouring it into silicone moulds.
- The temperature of the rheometer is set to facilitate handling of the bitumen sample, since it is a viscoelastic material with viscosity that varies with temperature. The test temperature was chosen to be 60 °C, and the loading frequency was set at 1.59 Hz, using a plate-plate geometry with a 25 mm diameter.
- Placing the sample into the rheometer and trimming it to the desired size is enabled by preheating the sample by the rheometer before the test begins. The sample is positioned between parallel measuring geometries.
- Oscillation of the sample, involving the introduction of sinusoidal shear strain into the bitumen sample within the linear viscoelastic region.
- Cleaning of the instrument is achieved by heating the bitumen sample to 120 °C and wiping the working surface of the rheometer [10].

Aging index (AI)

The aging index of bituminous binders is a value evaluated in road construction to determine the susceptibility of the binder to physical and chemical changes caused by oxidation, UV radiation, and other environmental factors. The aging index of bituminous binders can be assessed in relation to several different initial values, with the most common ones being penetration, softening point, ductility, and viscosity. In this work, aging indices are calculated from the complex shear modulus $G*$ and the phase angle δ. The aging index is computed as a ratio or difference between the initial values of unaged and aged binders, meaning that a higher value indicates a higher susceptibility of the binder to changes due to aging.

Tested materials

Several bituminous binders were used for conducting the tests. The primary reference binder is the common paving grade bitumen used in the Czech Republic, class 50/70. It was subsequently compared to polymer modified bitumen of class 45/80-65 from the same manufacturer. The last two binders are known as RC binders, used for their better integration into mixtures when using reclaimed asphalt in production. These RC binders belong to class 45/80 RC and are of different origins, one being Austrian and the other German, allowing for a comparison of different approaches to RC binders in Europe. All binders are listed in Tab. 1.

Tab. 1 Tested materials and their designation.

Bitumen	Origin	Designation
Pavement grade bitumen 50/70	Austria	50/70
Polymer modified bitumen 45/80-65	Austria	45/80-65
Polymer modified bitumen 45/80-50 RC	Germany	45/80-50 RC – G
Polymer modified bitumen 45/80 RC	Austria	45/80 RC – A

3 RESULTS

Tab. 2 and Fig. 1 illustrate the changing values of the complex shear modulus based on the level of bitumen aging. Tab. 3 and Fig. 2 show the changing values of the phase angle according to the level of aging. In Tab. 4 and 5, as well as in Fig. 3 and 4, the values of the aging index are then depicted, separated by individual binders.

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Tab. 2 Dependency of *G** [kPa] based on binder tested at *T* = 60 °C and *f* = 1,59 Hz.

Designation	Non-aged	RTFOT	RTFOT+PAV
50/70	2.45	5.82	21.35
45/80-65	7.90	15.53	40.50
45/80-50 RC – G	3.19	7.42	28.20
45/80 RC – A	6.16	11.70	27.40

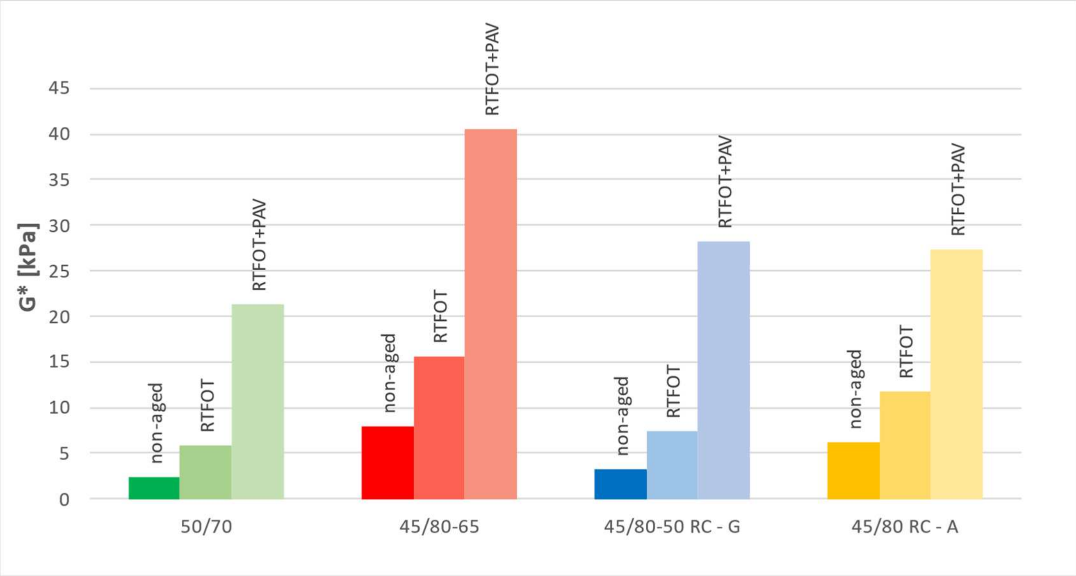

Fig. 1 Dependency of *G** [kPa] based on binder tested at *T* = 60 °C and *f* = 1.59 Hz.

Tab. 3 Dependency of phase angle [°] based on binder tested at *T* = 60 °C and *f* = 1.59 Hz.

Designation	Non-aged	RTFOT	RTFOT+PAV
50/70	85.75	81.47	73.11
45/80-65	60.32	57.16	53.66
45/80-50 RC – G	80.186	75.85	64.72
45/80 RC – A	56.40	53.36	50.77

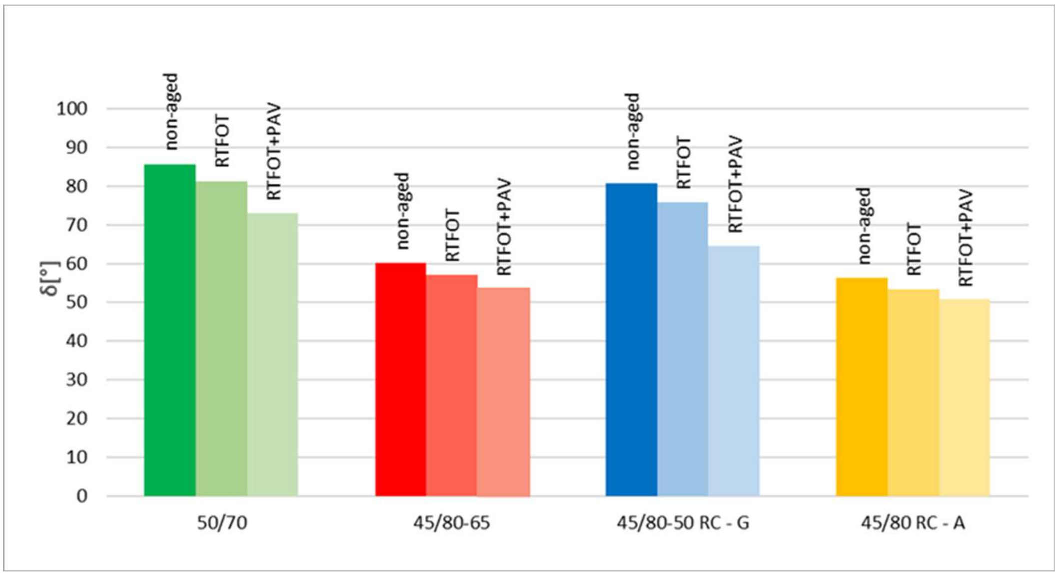

Fig. 2 Dependency of phase angle [°] based on binder tested at *T* = 60 °C and *f* = 1.59 Hz.

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Tab. 4 Aging index by G^* based on binder tested at T = 60 °C and f = 1.59 Hz.

Designation	Aging index – non-aged	Aging index – RTFOT	Aging index - RTFOT+PAV
50/70	1	2.37	8.71
45/80-65	1	1.97	5.13
45/80-50 RC – G	1	2.33	8.85
45/80 RC – A	1	1.90	4.45

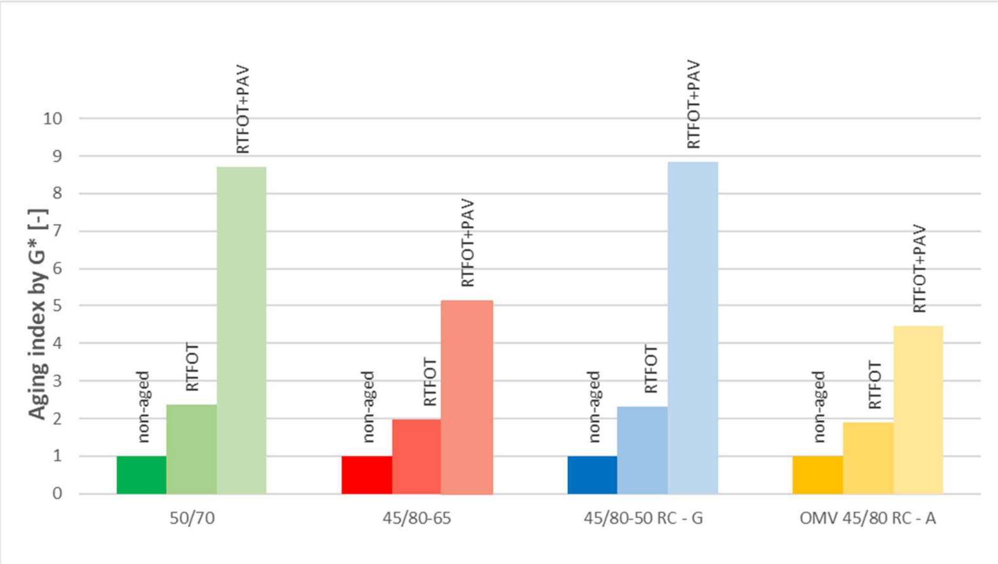

Fig. 3 Aging index by G^* based on binder tested at T = 60 °C and f = 1,59 Hz.

Tab. 5 Aging index by phase angle based on binder tested at T = 60 °C and f = 1.59 Hz.

Designation	Aging index – non-aged	Aging index – RTFOT	Aging index - RTFOT+PAV
50/70	0	4.28	12.64
45/80-65	0	3.16	6.66
45/80-50 RC – G	0	5.01	16.14
45/80 RC – A	0	3.04	5.63

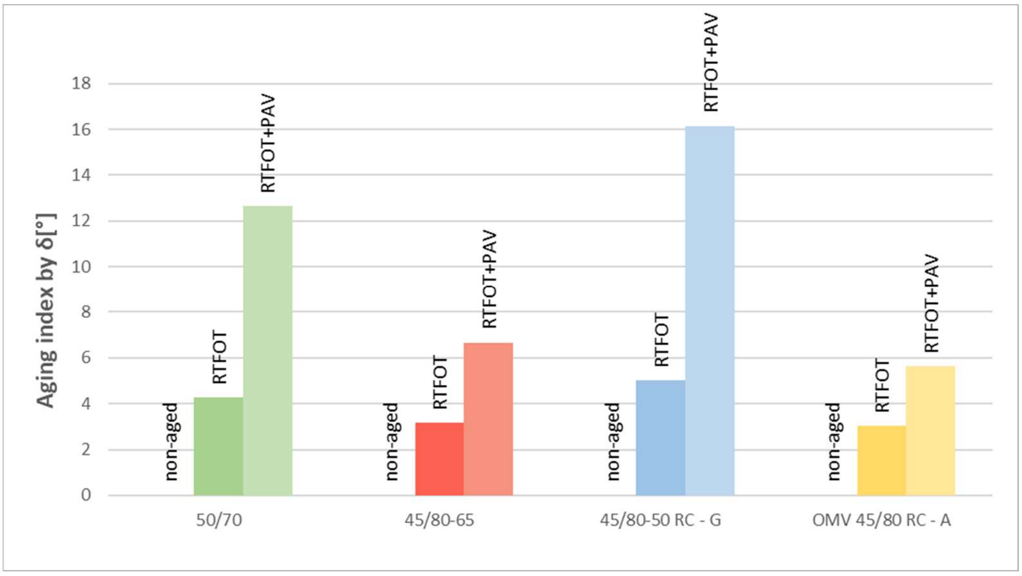

Fig. 4 Aging index by phase angle based on binder tested at T = 60 °C and f = 1.59 Hz.

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4 DISCUSSION

The previous results demonstrate the dependency of G^* and δ on the level of aging for individual binders. In Fig. 1, it is evident that the modified binder 45/80-65 achieves the highest values of the complex shear modulus, while the common paving grade bitumen of class 50/70 attains the lowest values, as expected. From this Fig., it can be deduced that binders 45/80-65 and 45/80 RC – A exhibit the highest resistance to deformation. In general, all of the tested binders become stiffer after aging.

When comparing the resulting phase angles, the highest values are achieved by bitumen binders 50/70 and 45/80 50 RC – G. This is due to the composition and production of RC bitumen binders in Germany, which are softer and less modified than Austrian bituminous binders and thus behave more like paving grade bitumen, meaning they are the least elastic among the tested samples. In contrast, the modified bituminous binder 45/80-65 and RC bituminous binder 45/80 RC – A are highly elastic and achieve similar values, as Austrian RC bituminous binders are heavily modified.

The aging index calculated from the complex shear modulus shown in Fig. 3, was calculated as the ratio of the resulting complex shear modulus values of the aged and unaged bitumen binders. The most significant changes due to aging, with respect to the complex shear modulus, occurred for bituminous binder 50/70 and the German bituminous binder 45/80 50 RC – G. These two binders are thus the most affected by aging, with their properties changing most significantly after exposure to short-term and long-term aging using the RTFOT+PAV method.

On the last graph, Fig. 4, the aging index calculated from the phase angle of individual bituminous binders at different aging stages is depicted. This index was calculated as the difference between the resulting phase angle values of bituminous binders. Once again, the most significant changes in binder properties due to aging were observed for bituminous binders 50/70 and 45/80 50 RC – G. As with the previous Fig. 3, the change is most apparent when the samples are exposed to aging through the RTFOT+PAV method. These two binders, which exhibited the most significant changes in binder behaviour due to aging, partially lost their ability to undergo plastic deformation. For the other two bitumen binders, 45/80-65 and 45/80 RC – A, the value of the aging index is relatively low on both Fig. 3, and Fig. 4, indicating higher resistance to aging for these binders.

5 CONCLUSION

The aim of this article was to demonstrate the change in mechanical properties due to aging, whether short-term or long-term, for bituminous binders used in Central Europe. To assess the susceptibility of individual binders to aging, an aging index was used, which was calculated for the complex shear modulus as the ratio of the moduli of aged and unaged binders. The aging index was then expressed as the difference in phase angle values between unaged and aged binders in absolute terms.

The testing confirmed that with aging, the value of the complex shear modulus increases while the phase angle decreases. From the figures, it is evident that modifications have a positive impact on binders when evaluating them from the perspective of aging.

From the resulting values, it can be inferred that polymer modified binders 45/80-65 and especially 45/80 RC – A exhibit the most favorable results in terms of resistance to aging. The reason why the Austrian binder 45/80 RC – A shows better resistance to aging than the German binder of the same class, 45/80 RC – G, is the Austrian approach to RC binders, where RC binders are heavily modified and have better durability. The concept of German binders differs in their approach to RC binders. Their RC binder is softer and theoretically should provide better integration with aged binders in asphalt mixtures with reclaimed asphalt. This difference might be noticeable in the thermal sensitivity of binders, for example, in the softening point test, which could be a topic for further research.

It cannot be directly concluded that the Austrian RC binder is better for asphalt mixtures with reclaimed asphalt because it would be necessary to test the mixed binder with aged binder from the mixture, which is referred to as blended binder.

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