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Ageing effect on the relaxation properties of bitumen

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ABSTRACT: The ageing of bitumen has a significant impact on the mechanical behavior of asphalt concrete. In this study, Dynamic Shear Rheometer (DSR) tests were utilized to investigate the effect of ageing on the relaxation properties of bituminous materials. PEN 70/100 bitumen films with thickness of 2 mm were exposed to laboratory ageing at various conditions. Specifically, different combinations of ageing time, temperature and pressure were applied on the bitumen films. Three evaluation indices, explicitly the shear stress at 0 s and 100 s, the ratio of shear stress at 0 s and 100 s and the time that shear stress reduce to 50% and 25% of the initial, were used to determine the evolution of the relaxation properties of bitumen. The results show that, in comparison to fresh bitumen, aged samples show higher residual shear stresses after relaxation and are more susceptible to stress accumulation thus cracking. In addition, temperature, followed by pressure and ageing time, was found to have the strong impact on bitumen ageing.

1 INTRODUCTION

In the Netherlands, ravelling of porous asphalt pavements is a major concern. Ageing of bituminous materials is believed to be one of the major causes. The mechanical properties of bitumen, as of all organic substances, evolve with time. It is well known that as bitumen ages its ductility and penetration index are reduced while the softening point is increased (Lesueur 2009). Ultimately, the viscosity of the bitumen is increased and bitumen becomes stiffer. This may cause the mixture to become excessively brittle and susceptible to fatigue damage and cracking at lower temperatures (Kliewer 1995).

In the past, research has shown that typical bitumen properties such as viscosity, penetration, softening point and ductility had a good correlation with ageing (Kandhal 1984). At that time the level of ageing was expressed as a reduction in penetration, an increase in softening point or as the ratio of viscosities, always in relation with the unaged (fresh) condition. Recently, more and more researchers used dynamic shear rheometer (DSR) to investigated the effect of ageing on fatigue and rheological properties of bitumen (Hofko 2016). The results showed that both complex shear modulus and fatigue life increase with ageing. However, these results cannot explain why aged bitumen is more susceptible to stress accumulation thus cracking.

The main objective of this study is to determine the changes in the relaxation properties of bitumen due to ageing by means of DSR tests. For this, bitumen films were aged in the laboratory at various ageing time intervals, temperatures and pressures. On the basis of the experimental results, three evaluation indices were used to analyze the changes in the relaxation properties of aged bitumen. Specifically, shear stress at 0 s and 100 s, the ratio of shear stress at 0 s and 100 s and the time that shear stress reduces to 50% or 25% of its initial value were selected. In addition, the impact of various factors (ageing time, temperature and pressure) on ageing from strong to weak is determined.

2 MATERIALS AND AGEING METHODS

2.1 Materials

The PEN 70/100 bitumen, which is one of the most commonly used in Netherlands, was used in this study. Table 1 shows the main physical and rheological properties of the examined bitumen.

Table 1. Specifications of PEN 70/100 at Fresh (Unaged) State.

Property	Unit	PEN 70/100
Penetration at 25 °C	0.1 mm	70-100
Softening point	°C	43-51
Dynamic viscosity at 60 °C	Pa s	160
Complex shear modulus at 1.6 Hz & 60 °C	kPa	1.8
Phase angle at 1.6 Hz & 60 °C	°	88

2.2 Ageing method

In this study, bitumen films with 2 mm thickness were aged by two different ageing methods: oven ageing and PAV (Pressure Ageing Vessel) ageing. Oven ageing was applied for various ageing time and temperatures, while PAV ageing was applied for various ageing pressures. Table 2 summarizes the various ageing processes that were considered.

Table 2. Ageing program.

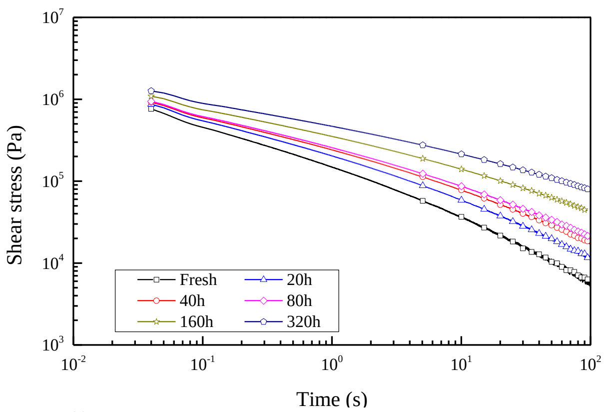
Ageing Method	Temperature (°C)	Pressure (atm)	Ageing Time(h)
Oven	100	1	20, 40, 80, 160, 320
Oven	50, 150, 200	1	40
PAV	100	5, 10, 15, 20	40

3 EXPERIMENTAL METHOD

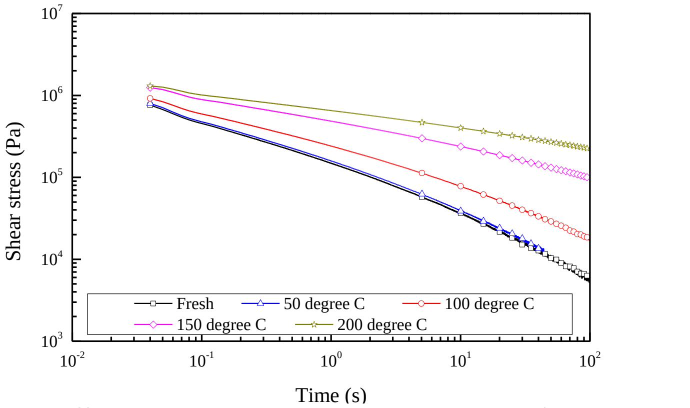
In order to study the changes in the relaxation properties of the bitumen due to oxidative ageing, DSR tests were performed. The bitumen samples were tested using the parallel-plates configuration with 8 mm plate diameter and 2mm gap at 0 °C. Initially, the linear viscoelastic (LVE) strain range of bitumen samples was determined using amplitude sweep tests. The relaxation tests were performed with 1% shear strain at the beginning, followed by a relaxation period of 100 seconds. The data collection frequency was 100 Hz.

4 RESULTS AND DISCUSSION

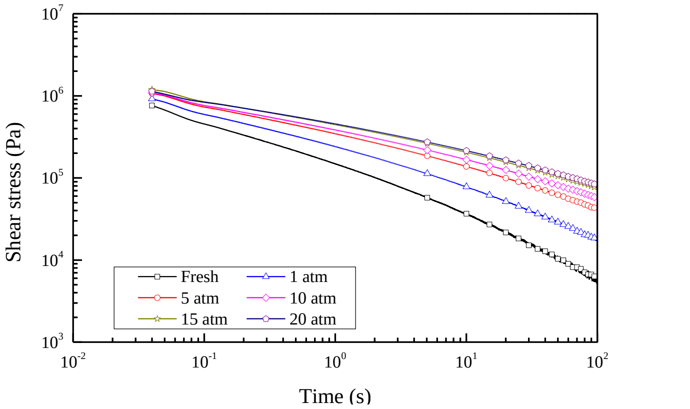
A minimum of three replicate samples for each ageing condition were tested using the DSR. Figure 1 shows the relationship between shear stress and relaxation time with increased ageing time, temperature and pressure.



(a) Different ageing time (oven ageing at 100 °C and 1 atm).

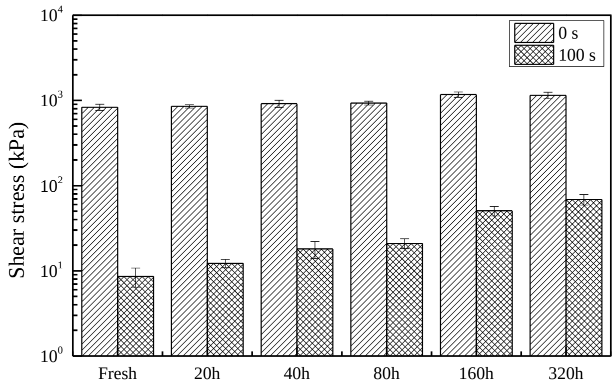


(b) Different ageing temperatures (oven ageing for 40 h at 1 atm).

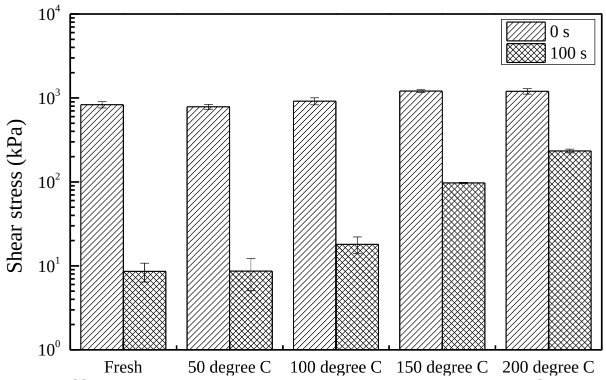


(c) Different ageing pressures (PAV ageing for 40 h at 100 °C).
Figure 1. Relaxation curves of PEN 70/100 at different ageing conditions.

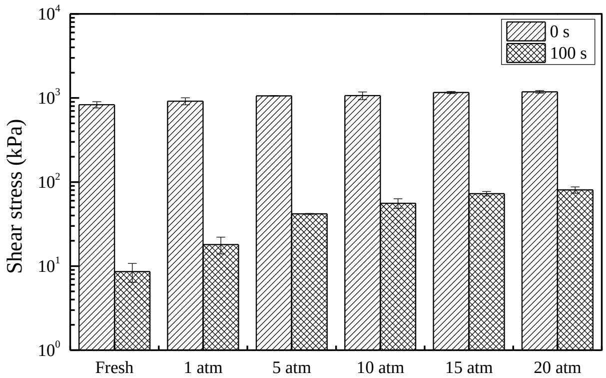
Figure 1 shows there is a good logarithmic relationship between shear stress and relaxation time. Relaxation curve moves up with ageing, thus indicating that, at the same relaxation time, the shear stress of bitumen increases with ageing. In other words, relaxation modulus increases with ageing. Comparing Figure 1 (a), (b) and (c), it can be observed that temperature is the most influential parameter for ageing, probably because of the fact that the ageing rate coefficient increases exponentially with temperature based on the Arrhenius equation. In order to further analyse the relaxation properties of aged bitumen, the absolute values of shear stress at 0 s and 100 s are plotted in Figure 2, which denote the stress state of bitumen at the initial and end time of relaxation.



(a) Different ageing time (oven ageing at 100 °C and 1 atm).



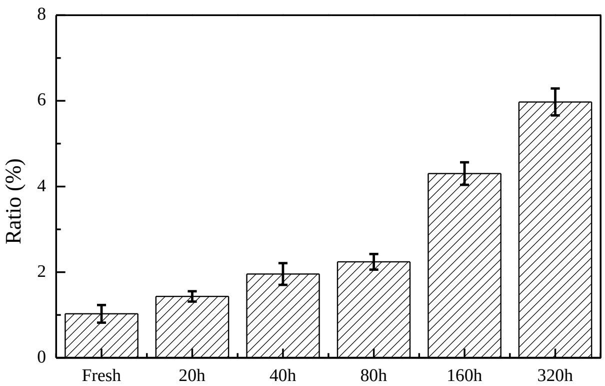
(b) Different ageing temperatures (oven ageing for 40 h at 1 atm).



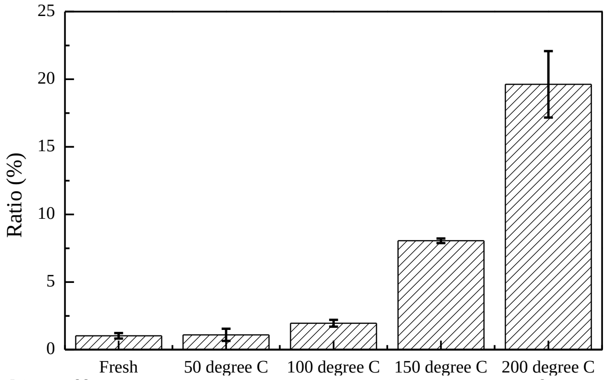
(c) Different ageing pressures (PAV ageing for 40 h at 100 °C).

Figure 2. Shear stress of PEN 70/100 at 0 s and 100 s under different ageing conditions.

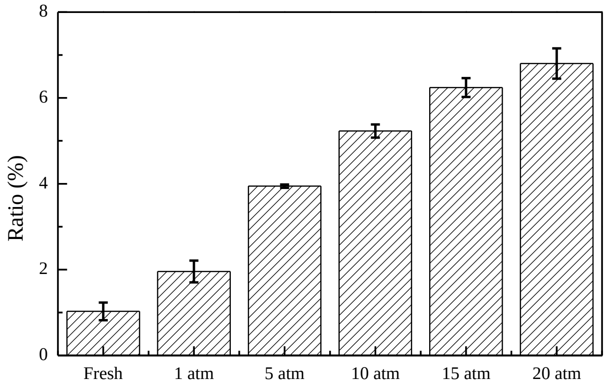
In Figure 2, the initial shear stress (shear stress at 0 s) of bitumen samples subjected different ageing conditions are in order of 1000 kPa. The initial shear stress of the most highly aged sample (320 h, 200 °C or 20 atm) is about 1.4 times larger than that of fresh bitumen. However, after a relaxation period of 100 s, the shear stress of the 320 h aged sample, the 200°C aged sample and the 20 atm aged sample was still 68.73 kPa, 233.78 kPa and 80.63 kPa, respectively, which is more than 10 times higher than that of fresh bitumen. Hence, the residual shear stresses after the same relaxation time are higher for the aged samples. Figure 3 shows, the ratio of residual shear stress (at 100 s) over the initial stress at (0 s) describes the relaxation rate at a specific time. Higher ratios indicate that bitumen can accumulate higher stresses after the same number of loading.



(a) Different ageing time (oven ageing at 100 °C and 1 atm).



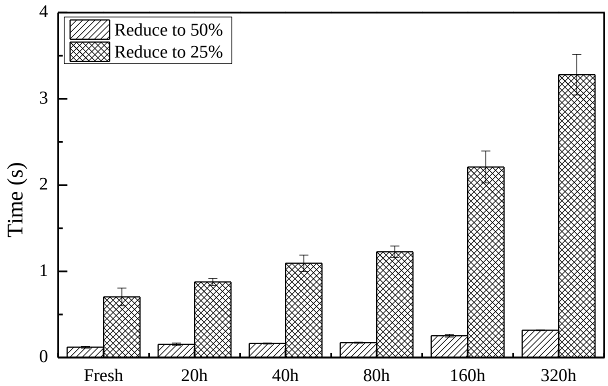
(b) Different ageing temperatures (oven ageing for 40 h at 1 atm).



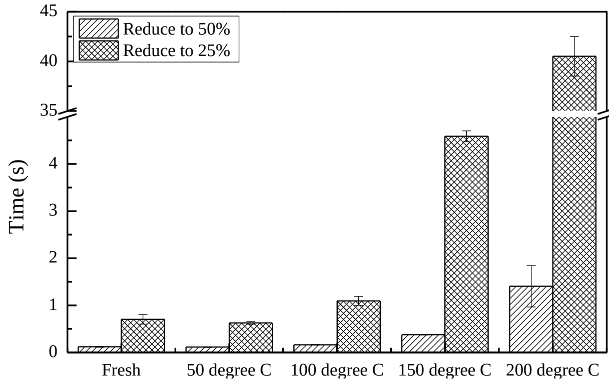
(c) Different ageing pressures (PAV ageing for 40 h at 100 °C).

Figure 3. Ratio of shear stress at 100 s and 0 s under different ageing conditions.

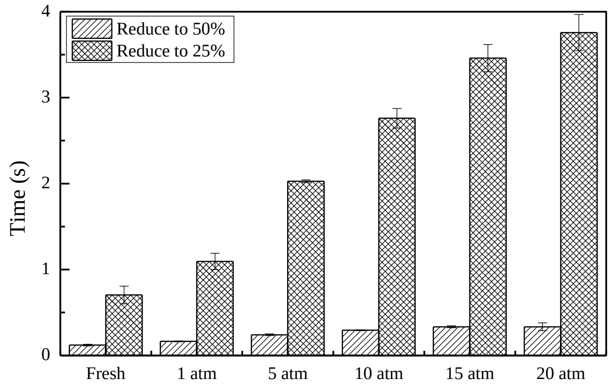
The results shows that the shear stress ratio increases with ageing. For the fresh bitumen, only 1.03 % of the initial shear stress remained after 100 s relaxation, however more than 6% of initial shear stress remained in the aged sample after relaxation. Especially, for the sample aged at 200 °C (Figure 3 (b)), about 20% of initial shear stress remained after relaxation. The results show that aged bitumen results to higher stress ratios, suggesting that it can accumulate higher stress after the same number of loading. Due to the fact that there is continuous traffic loading, the relaxation time of bitumen needs to be short so as to prevent stress accumulation in the pavement. Figure 4 shows, relaxation time when shear stress reduce to 50% or 25% of the initial stress.



(a) Different ageing time (oven ageing at 100 °C and 1 atm).



(b) Different ageing temperatures (oven ageing for 40 h at 1 atm).



(c) Different ageing pressures (PAV ageing for 40 h at 100 °C).
Figure 4. Time that shear stress reduce to 50% and 25% of the initial stress.

The relaxation time, at which shear stress reduce to 50% and 25% of the initial stress, increases with ageing. An increase of the relaxation time can be explained by the fact that the viscosity of bitumen increases due to ageing. For fresh bitumen, the shear stress reduces to 25% of its initial value in one second. However, this time increases for the 320 h aged sample and 20 atm aged sample, which need 3.28 s and 3.76 s, respectively. For the bitumen sample aged in the oven at 200 °C, the relaxation time to reach 25% decay in stress is more than 40 s. Longer relaxation times denote materials that are more susceptible to accumulate stresses.

Finally, the results show that temperature has a stronger impact on bitumen with respect to ageing, followed by pressure and ageing time. This can be attributed to the fact that the rate of ageing increases exponentially with temperature based on the Arrhenius equation (Boysen 2015), whereas it increases linearly with pressure based on the Henry's law (Prapaitrakul 2009). Hence, high temperature ageing is an efficient way of accelerating ageing.

5 CONCLUSIONS

The work presented in this paper shows the preliminary results of a broad study on the effect of ageing on the mechanical properties of bitumen and asphalt concrete. Studying only the stiffness and fatigue behaviour of bitumen cannot directly characterize the degradation of its properties due to ageing, because both stiffness and fatigue life increase with ageing. This work focuses specifically on the influence of ageing on the relaxation properties of bitumen. For this reason, a series of ageing experiments were performed on 2 mm thickness bitumen films at different ageing time intervals, temperatures and pressures. DSR tests were carried out to determine the changes in response of aged bitumen.

On the basis of the relaxation curves, three evaluation indices were used to analyse the evolution of the relaxation properties of bitumen. The results show that aged bitumen has higher initial stresses (at 0 s) and higher residual stresses after relaxation (at 100 s). Specifically, the value of shear stresses at 100 s is more than 10 times higher than that of fresh bitumen. The ratio of shear stress at 100s and the initial stress shows that only 1% of the initial shear stress remained in the fresh sample, while 6% remained in the aged sample after relaxation. The time that the shear stress reduces to a quarter of the initial stress increases from 0.7 s to 4 s after ageing. Especially for highly temperature (200 °C), the time increased to 40 s. In conclusion, ageing cause bitumen to become more susceptible to stress accumulation, thus more prone to cracking.

As a continuation of this research, an ageing damage model will be developed. Finite element simulations will be performed to demonstrate the influence of ageing on the relaxation response of bituminous materials.

6 ACKNOLEDGMENTS

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