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Laboratory and field ageing of asphalt mixtures

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ABSTRACT: Ageing of bituminous materials contributes to various forms of pavement failures, thus leading to the degradation of pavement performance. To understand the evolution of pavement performance, the development of a proper laboratory protocol to simulate long-term ageing process of asphalt mixtures is of uppermost importance. In this study, the porous and dense asphalt slabs with thickness of 5 cm were exposed to oven ageing at 85 °C for 3 and 6 weeks in the laboratory. Cyclic Indirect Tensile tests were performed to investigate the effect of ageing on the mechanical properties of asphalt mixture. The results were used to correlate with the change in the mechanical properties of the porous and dense pavement in the field. Pavement test sections were constructed in 2014 and have been exposed to actual environmental conditions since then. To study the temporal changes in the mechanical properties of the pavements, asphalt cores were collected from the test sections annually. The results show that porous asphalt has a higher ageing rate than dense asphalt due to its high porosity. Porous asphalt aged at 85 °C for 3 and 6 weeks in the laboratory have the same stiffness change as that aged 3 and 3.5 years in the field, respectively. Dense asphalt aged at 85 °C for 3 weeks in the laboratory have the same stiffness change as that aged 4 years in the field.

1 INTRODUCTION

The majority of Dutch national highway and provincial road network is paved with a top layer of porous asphalt (PA) and dense asphalt (SMA, stone matrix asphalt), respectively. The performance of these pavements change over time due to ageing (Petersen & Glaser 2011). Though this may benefit the pavement through enhanced rutting resistance, ageing can cause or accelerate several distresses such as fatigue, low temperature cracking and moisture damage (Woo et al. 2008). A proper protocol to simulate the long-term ageing could contribute to the prediction of pavement performance in time and to the development of longer-lasting pavement materials.

The commonly used protocol to simulate long-term ageing process of bituminous materials is pressure ageing vessel (PAV). The test is performed on bitumen films with 3.2 mm thickness at temperatures between 90 and 110 °C under pressurized conditions (Lu & Isacsson 2002). Even though the protocol is widely accepted by the pavement industry worldwide, it has been reported that the PAV protocol cannot accurately simulate the long-term ageing condition for porous mixtures (Jing et al. 2019, van Lent et al. 2016). In addition, the performance of bitumen aged in a multiphase system (mixture) is different than ageing bitumen by itself. Ageing susceptibility does not only depend on the physicochemical properties of bitumen, but also depends on the interaction with filler, and mixture morphology which is essentially a result of aggregate packing, porosity, air void distribution and their interconnectivity (Erkens et al. 2016, Huang & Zeng 2007).

The goal of this study is to evaluate the behavior of porous and dense asphalt mixtures ageing both in the laboratory and field. The main objectives are to (i) determine the changes in the mechanical properties of porous and dense asphalt due to laboratory and field ageing by means of Cyclic Indirect Tensile test, (ii) correlate the results of laboratory ageing with those of field ageing.

2 MATERIALS AND AGEING METHODS

2.1 Asphalt mixture design

The same asphalt mixture design was used for mixtures produced in the laboratory and laid in the field test sections for both porous (PA) and dense (SMA) asphalt. Moreover, the laboratory slabs and test sections were produced using the same bitumen, filler and aggregate types. Table 1 shows the specifications of the used materials. The bitumen content was 5.0 % and 6.4 %, and the target air void (AV) content was 20 % and 5 % for the PA and the SMA mixtures, respectively. The gradations of both mixtures are shown in Figure 1.

Table 1. Materials specifications.

Name	Type	Properties	
Bitumen	PEN 70/100	Penetration at 25 °C (dmm)	70-100
		Softening point (°C)	43-51
Filler	Wigro 60K	Density (kg/m3)	2780
		Hydrated lime content (%)	25
Aggregate	Bestone	Density (kg/m3)	2740
		Nominal Max. size (mm)	16

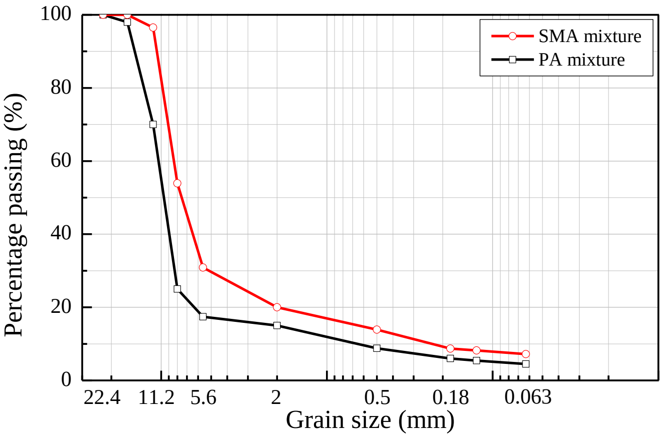


Figure 1. Gradations of PA and SMA mixtures.

2.2 Laboratory ageing

Two asphalt slabs (namely one PA and one SMA) were prepared in the laboratory. The asphalt slabs were 5 cm in thickness, and 50 cm in length and width. The asphalt slabs were compacted using a roller compactor to reach the design density and void content. Then the compacted slabs were cut into three smaller slabs (16x50x5 cm). One of these slabs was used as a reference sample at the fresh (unaged) condition. The other two slabs were aged in the oven at 85 °C for 3 and 6 weeks, respectively. In order to prevent the slabs from deforming during ageing and simulate the field ageing situation, slabs were wrapped by duct tape on the four sides and the bottom. After laboratory ageing, three core samples (10 cm in diameter and 5 cm in thickness) were drilled from each slab.

2.3 Field ageing

The construction phase of the test sections started with the removal of the existing old pavement surface, which had 10 cm thickness. After the milling process, a bitumen emulsion tack coat layer was sprayed on the surface. Then the new stone asphalt concrete (STAC) layer of 6 cm thickness was laid first as the base layer, and the 5 cm thickness top porous (PA) and dense (SMA) asphalt layers were placed on the left and right lanes separately. The layers were compacted using a roller compactor. The construction of the test sections was done in October 2014. Since then the test sections have been continuously exposed to the environment and three core samples with a diameter of 10 cm and a thickness 5 cm are drilled from the PA and SMA layers every year.

3 EXPERIMENTAL METHODS

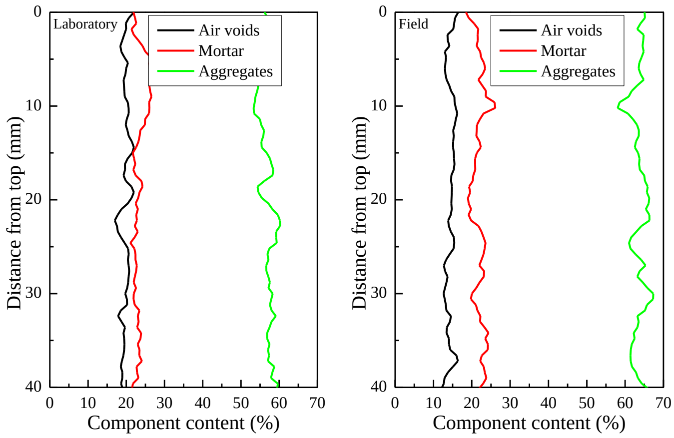
To verify that the volumetrics of the laboratory- and field-produced samples are comparable, the internal morphology of the cores (at unaged conditions) was determined by means of X-ray CT scanner. The samples were scanned along the height with a vertical resolution of 0.6 mm. Then the image processing software Simpleware was used to identify and quantify the different phases of the mixtures.

To study the temporal changes in the mechanical properties of the porous and dense asphalt mixture due to oxidative ageing, Cyclic Indirect Tensile tests (IT-CY) were performed according to NEN-EN 12697-26. The dynamic modulus of core samples was determined using the Universal Testing Machine (UTM) at five frequencies (i.e. 0.5, 1, 2, 5 and 10 Hz) and four testing temperature (i.e. 0, 10, 20 and 30 °C). Three replicate samples for each ageing condition were tested. Each sample were conditioned at the testing temperature for 4 hours before testing to equilibrate sample’s temperature.

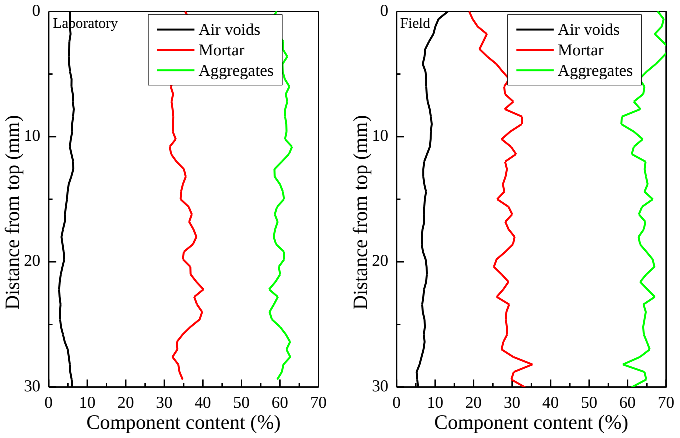
4 RESULTS AND DISCUSSION

4.1 Volumetrics composition of the mixtures

On the basis of the CT scan images, the distribution of the voids, mortar and aggregates over the height of the samples (PA and SMA) was determined. Figure 2 shows the results for the laboratory and field samples. Overall, Figure 2 shows that PA has higher air void content as expected and lower mortar content in comparison with SMA. In addition, the laboratory-produced PA sample has slightly higher void content than the PA sample cored from the field. Considering the target air void content of 20%, it appears that the test sections were over-compacted resulting to a lower air void percentage. In contrast, SMA samples from the laboratory and field slight differences in the percentage of each component.



(a) PA mixtures (left: laboratory sample, right: field sample)



(b) SMA mixtures (left: laboratory sample, right: field sample)

Figure 2. Distribution of air voids, mortar and aggregates over the height of the core sample. (mortar is the mix of bitumen, filler and fine sand with particle size less than 2 mm)

4.2 Mechanical properties of the mixtures

The Time-Temperature Superposition (TTS) principle was used to generate the master curves of the dynamic modulus at a reference temperature of 20 °C. Figure 3 illustrates the evolution of dynamic modulus for PA mixtures due to laboratory and field ageing. The black dashed lines denote the results of the laboratory samples and the colored lines denote the results of the field samples.

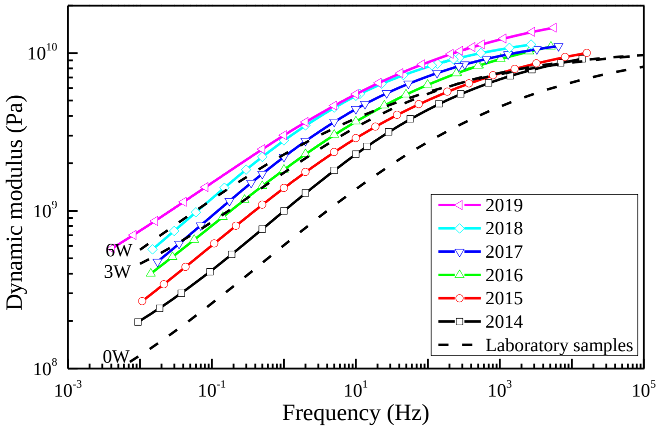


Figure 3. Dynamic modulus of PA samples at different ageing conditions.

Figure 3 shows that that the field sample after production and construction (sample in 2014) is stiffer than the sample after production in the laboratory (sample 0W). This could be attributed to the differences in the air void content between the field PA sample (15% AV) and the laboratory PA sample (20% AV), with the latter being more porous (Figure 2) possible due to the application of higher compaction effort. Such difference in the air void content would result in differences in the ageing rates of the laboratory-aged and the field-aged mixtures. The laboratory-aged samples would essentially have a higher ageing rate than the field samples based on their volumetrics composition. However, it is still meaningful to correlate the rates of laboratory and field ageing. Considering that the absolute dynamic modulus values of PA samples from laboratory and field are significantly different at fresh condition, the change in the dynamic modulus is used to correlate laboratory and field ageing. To be specific, the change in the dynamic modulus at 10 Hz (since it is a commonly used frequency in a dynamic test) and 20 °C (room temperature) of PA samples is selected and plotted in Figure 5. The results show that after 3 weeks of ageing the laboratory-produced PA samples have approximately the same stiffness change as the PA cores after 3 years of ageing in the field. Moreover, the PA samples after 6 weeks of laboratory ageing have the same stiffness change as the PA sample that were aged 3.5 years in the field.

Figure 4 demonstrates the evolution of dynamic modulus for SMA mixtures due to laboratory and field ageing. Unfortunately, there were no cores taken from the SMA section right after laying in 2014. Since SMA samples from the laboratory and field have the similar percentage of each component, as shown in Figure 2, it is assumed that the initial stiffness (at fresh state) for the field sample is similar to the laboratory produced sample. Figure 4 shows that 3 weeks of laboratory ageing simulate 4 years of field ageing for the SMA sample. Based on the results, the stiffness levels of the SMA samples after 6 weeks of laboratory ageing exceed the stiffness of 5 years of field ageing.

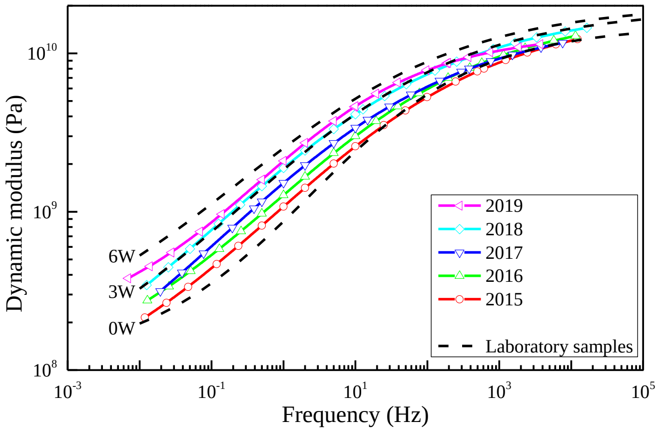


Figure 4. Dynamic modulus of SMA samples at different ageing conditions.

Finally, on the basis of the results in Figure 3 and 4, the temporal evolution of dynamic modulus (at 10 Hz and 20 °C) for both mixtures after field and laboratory ageing were calculated and plotted in Figure 5. The results clearly show that the rate of stiffness change is higher for the PA sample than for SMA samples for both laboratory and field ageing conditions. This is mainly because of the high void content of PA, which leads to an inherently high sensitivity of these mixtures to oxidative ageing. After a certain time, the stiffness of the PA mixtures tends to become stable and that occurs at an earlier time than for the SMA mixture. In addition, the difference in the stiffness changes between two mixtures is higher for field ageing than for the laboratory ageing. This could probably be related to other environmental factors; for instance moisture and ultraviolet radiation can contribute to pavement ageing and you would expect that their effects on the two mixtures to be different due to their distinct morphologies.

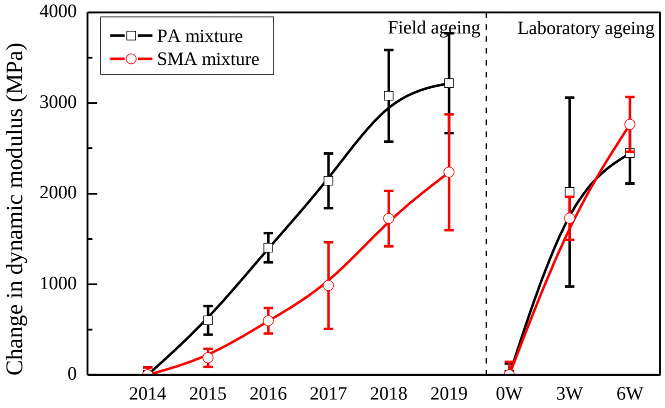


Figure 5. Temporal changes in the dynamic modulus (at 10 Hz and 20 °C) of PA and SMA mixtures at different ageing conditions.

5 CONCLUSIONS

To better understand the long-term behavior of asphalt pavements and to select proper materials and structures that can delay potential pavement failure, the development of accelerated ageing protocols is necessary and crucial. In this study, the ageing susceptibility of porous and dense asphalt mixtures was investigated using field aged cores from test sections (constructed in 2014) and laboratory aged cores (oven ageing at 85 °C for 3 and 6 weeks) taken from 5 cm thickness asphalt slabs. A series of stiffness tests were conducted on asphalt cores, which were taken from the laboratory-aged slabs and the pavement sections.

The CT scan results show that there is a difference between laboratory and field compaction, especially for the PA mixture. To be specific, the laboratory-produced PA sample has higher void content than the field PA sample, while for the SMA samples slight difference in the voids content were found. This differences in the voids content could higher the application of accelerated ageing protocols for the prediction of the ageing sensitivity of mixtures in the field. To overcome this issue, the ageing rate (namely the temporal change of stiffness due to ageing) was used as the ageing sensitivity index. The results show that change in stiffness for both laboratory and field ageing is greater for the porous than the dense mixture, because of the high porosity of porous asphalt that allows air (oxygen) to easily flow into the mixture. Due to its high ageing rate, the porous mixture is expected to reach a constant stiffness value faster than the dense mixture, as the rate of stiffness increase tends to decrease with time. Overall, the difference of the ageing rates between the two mixtures is larger when the mixtures are aged in the field. This could probably be related to other environmental factors; for instance moisture and ultraviolet radiation can contribute to pavement ageing. From a comparison between the results of laboratory- and field-aged samples, it can be concluded that porous asphalt aged at 85 °C for 3 and 6 weeks in the laboratory has the same stiffness change as the field aged 3 and 3.5 years, respectively. On the other hand, dense asphalt aged at 85 °C for 3 weeks in the laboratory has the same stiffness change as the field-aged 4 years. The stiffness of the dense samples after 6 weeks of laboratory ageing would probably exceed the stiffness of samples after 5 years of field ageing.

As a continuation of this research, the core samples will be cut into three slices from top to bottom. Bitumen will be extracted from each slice. Chemical and rheological tests will be performed on the recovered bitumen to investigate the ageing profile of the mixtures. Results of the recovered bitumen from the laboratory- and field-aged samples will be used to verify the relationship between laboratory and field ageing.

6 ACKNOWLEDGMENTS

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