EFFECTS OF MOISTURE ON THE MECHANICAL AND VISCOELASTIC BEHAVIOR OF ASPHALT MIXTURE UNDER REPETITIVE CYCLIC LOADING

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Abstract

Moisture exposure of the asphalt pavement leads to the loss of internal strength of the mixture and exacerbated distresses such as cracking and rutting. The moisture has a long-term aging effect on the bitumen binder and bitumen mastic (loss of cohesion) and stripping of bitumen from the aggregate surface (adhesion fail). Understanding the process of moisture damage in asphalt is very crucial because of its significant consequences on pavement life. However, its effect is very complex and there is no single theory to explain the damage processes. Currently, employing moisture sensitivity tests according to EN 12697-12 have the advantage to compare moisture sensitivity after short-term conditioning for 3 days at 40 °C between different materials. However, the test procedures consider a single load application, which is far from the actual repeated vehicular loads in the pavement life. To understand the effects of moisture under repetitive loads, this research follows the cyclic load indirect tensile fatigue test (ITFT) with a stress-controlled mode of loading. Three different aggregate sources combined with two types of bitumen binders were employed to prepare 100mm cylindrical specimens cored from laboratory prepared slab using a steel roller compaction. To study the moisture effects on self-healing (stress recovery) of the asphalt, a rest period was introduced at a predefined number of load cycles. The short-term moisture conditioned samples show that moisture has influenced the stiffness modulus, elastic horizontal strain, self-healing effects, and the fatigue life of the asphalt mixture. Moreover, the effect of aggregate and bitumen sources influences moisture sensitivity of asphalt mixture under cyclic loading. The addition of a surfactant additive has also shown the advantage to decrease the effects of moisture in asphalt mixture made with quartzite aggregate.

Keywords: moisture susceptibility, indirect tensile fatigue test, self-healing, stiffness recovery

1 Introduction

The moisture exposure of bituminous mixture is an inevitable problem that accelerates the structural degradation of pavement layers. The effect of moisture revealed by loss of stiffness in bitumen binder and bitumen mastic through diffusion and loss of adhesive bonds in bitumen mastic and aggregate interfaces [1, 2]. These losses of cohesion and adhesion of the mixture due to moisture susceptibility accelerate distresses like fatigue and rutting damage. The process of moisture damage composed multiple factors and very complex to understand. The moisture effect in the asphalt mixture can be evaluated with various testing procedures. However, the most acceptable procedure is the water sensitivity test according to EN 12697-12, that compares the strength of dry and moisture conditioned samples within a single load application to fail. Though the test forecasts the effect of moisture in different aggregate

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and bitumen combinations, it doesn't show the effect of moisture in fatigue performance of bituminous mixtures or stresses under cyclic load application. Similarly, the pavement exposed to repeated vehicular loading on its service life and it is important to simulate the traffic loads with the cyclic (periodic) loading during the sample testing in the laboratory. Load factors such as stress amplitude, load wave pattern and loading time are significantly affecting the fatigue damages of samples in the laboratory.
The fatigue performance of asphalt depends on multiple factors including the aggregate gradation, air void content, traffic load characteristics and environmental conditions such as temperature and moisture. The mixture factors such as mixture formula, material properties of aggregate and bitumen binder have also major contributions to the fatigue performance of bituminous mixtures. The tensile strain that causes to develop the fatigue cracking exacerbated by the combined effects of traffic loads and moisture [3]. This study focuses on the impact of moisture against the performance of fatigue cracking of pavement layer made with the bituminous mixture. Results include changes in the mechanical behavior of asphalt mixture before and after moisture exposure and the degree of moisture effects to accelerate the fatigue cracking of bituminous mixtures.

2 Experimental study

2.1 Material and sample preparation

Performance of asphalt mixtures depends on aggregate sources, properties of bitumen binder, bitumen content, fillers, used additives, mixing gradation and air voids in the compacted mixture. In this research three aggregates, Basalt, Limestone, and Quartzite in combination with 30/45 and polymer modified 25/55-25A bitumen binders were assessed. The aggregates have different mineral compositions and have different responses against moisture exposure. Quartzite has high siliceous minerals, limestone contains a high amount of calcium mineral, and the basalt has minerals that contain calcium, magnesium, and iron. The liquid Wetfix BE surfactant adhesion promotor was used in one sample group of asphalt mixture made with the quartzite aggregate.
The laboratory experiment was carried out with a continuously graded binder course (AC 16) asphalt mixture with a maximum aggregate size of 16 mm, according to TL Asphalt StB 07/13. The percent of bitumen binder used varies between the aggregate's sources for reaching same volume proportion. The specification limits for the aggregate size distribution as shown in table 1.

Table 1 Aggregate gradation, bitumen, and air void content in tested asphalt samples

Sieve size [mm]	**Spec. % pass**	**Basalt**	**Quartzite**	**Limestone**
22.4	100 - 100	100	100	100
16	90 - 100	100	98.1	97.7
11.2	65 - 80	77.6	77.8	77.2
2	25 - 30	28.8	28.4	27.5
0.125	10-May	9.9	7.3	6.8
0.063	7-Mar	8.3	5.9	3.5
Limestone filler	-	6	6.5	0
Bitumen [%]	-	4.9	5.6	4.9
Air void [%]	30/45	7.0 – 7.4	6.7 – 7.3	6.9 – 7.4
	25/55-25A	7.2 – 7.4	6.6 – 7.3	6.7 – 7.4

Seven combinations of aggregates and bitumen were designed and for each combination, three cylindrical specimens tested for each of dry and moisture conditions. The cylindrical specimens (diameter 100 mm, height 60 mm) were cored from the slab prepared by compacting according to EN 12697-33. The moisture conditioning follows European standard EN 12697-12. Samples subjected to partial vacuum saturation for 30 min that reaches 6.7 KPa within 10 min after the start of vacuum followed by conditioning in a 40 ± 1 °C water bath and kept for 72 ± 4 hr.

2.2 Indirect tensile fatigue test (ITFT)

The tensile failure due to repetitive traffic load is the dominant mode of failure in asphalt mixture [4]. For the fatigue test, cyclic indirect tensile stress test according to EN 12697-24 annex F were employed, with a frequency of 10Hz at temperature of 20°C. The applied load amplitude of 0.35 MPa resulted in horizontal deformation within a strain range of between 100 μm/m to 400 μm/m, and the fatigue life of tested material between 10^3 and 10^6 load cycle applications.
During the laboratory test, the cyclic load paused for 7500 sec, when the stiffness modulus decreased to 80 % of the initial value ($0.8E^*_{ini}$), to study the healing effects. After the rest period, the load was continued unto failure. The horizontal and vertical deformations were recorded at each cycle and the testing was stopped automatically at a horizontal deformation of 1500 μm e or a maximum vertical deformation of 7000 μm, controlled by LVDTs.

2.3 Self-healing characteristics of asphalt

Asphalt mixtures have a self-healing property that helps to restore energy after vehicular loads. Self-healing illustrated by the recovery of stiffness modulus, and the healing effect highly depends on the length of rest periods [5, 6]. Therefore, these effects incorporated for rational explanations of asphalt mixtures damage in fatigue. Researchers criticized the large difference in fatigue characteristics between the laboratory and real road behavior [3, 5, 7]. Appling a continuous cyclic load does not simulate the actual pavement service life, because the traffic load is noncontinuous and random with different rest periods. In laboratory tests, the rest period for the self-healing effect is applied either at each single load cycle or after a predefined number of load cycles. The materials take a long testing time to damage with the existence of rest period between application of every single load. Even though the second method does not represent the in-situ pavement, it is better to insight the change of material properties [5]. Previous laboratory investigations showed that the material recovery increases as the duration of the rest period increase up to a certain time and then doesn't show further changes. After 45, 000 seconds of a rest period, the recovery capacity of the asphalt mixture becomes insignificant [5, 8].

3 Result and discussion

The asphalt pavement degradation due to repetitive vehicular load is explained by different theoretical frameworks. The most common one is dividing the degradation process into two phases. In first phase micro-cracking is initiated, which propagate, combine and grow to form the macro-cracks in the second phase [4]. As the cyclic load application increases, there is reduction of stiffness modulus and an increasing of the dissipated energy per load cycle, which can further be displayed as energy ratio [5, 9]. From the continuously measured vertical force and horizontal specimen deformation, stress and strain amplitude were calculated as well as the initial stiffness modulus, self-healing effects in the asphalt mixture for the rest period of 7500 sec paused at 80 % of the initial stiffness and the fatigue life using M_{akro} (maximum energy ratio) criteria were assessed.

3.1 Recovery of stiffness modulus

In this study, a rest period of 7500 sec applied when the stiffness modulus reached 80 % of E*ini. During the rest period, parameters such as stiffness modulus, phase angle, and deformations are recovered. The effect of moisture in bituminous mixture studied by examining the recovery capabilities of the materials after dry and moisture conditioning. The sample recovery potential evaluated based on the relative change of stiffness modulus between phase 1, just before rest period and phase 2 after the rest period.

$$\Delta E^*_R = \frac{E^*_{ARP} - E^*_{BRP}}{E^*_{BRP}} \cdot 100\ [\%] \qquad (1)$$

Where E^*_{ARP} is the stiffness modulus after rest period, E^*_{BRP} before the rest period and ΔE^*_R is % of recovered stiffness modulus. For calculating E^*_{BRP} and E^*_{ARP}, the average stiffness modulus of last five cycles before the rest period and the average value between 11th and 15th cycles after the rest period were considered. The percent change of the stiffness modulus for each group of samples shown in Figure 1. Compared with the dry samples, the moisture conditioning of asphalt samples shows lower recovery of stiffness.

As shown in Figure 1 in all aggregate and bitumen combinations, the moisture reduced the recovered stiffness modulus. The viscoelastic property of bituminous mixture is coming from the properties of bitumen binder. Hence, the effect of moisture reduces the elastic nature of bitumen binder and the integration between bitumen binder and aggregate.

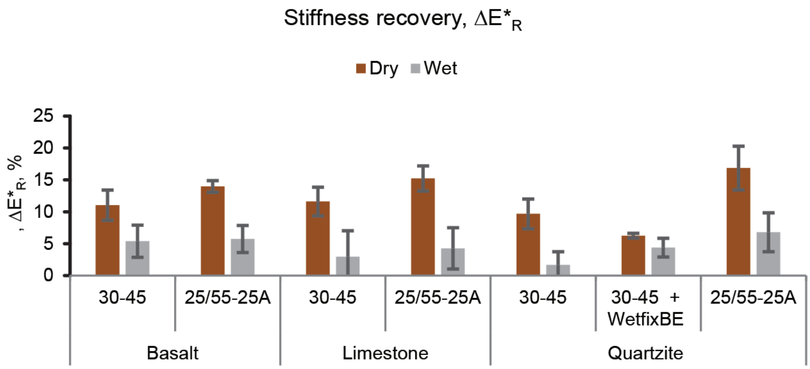

Figure 1 Stiffness recovery after the rest period [%]

3.2 Energy ratio (N_{Makro})

According to EN 12697-24, Annex 7, the energy ration (E_{RN}) criteria used to evaluate the number of load cycles until failure. The maximum peak point of the product of stiffness modulus and corresponding number of load cycles, considered as the transition between micro and macro cracking (N_{Makro}) and used as criteria for fatigue failure.

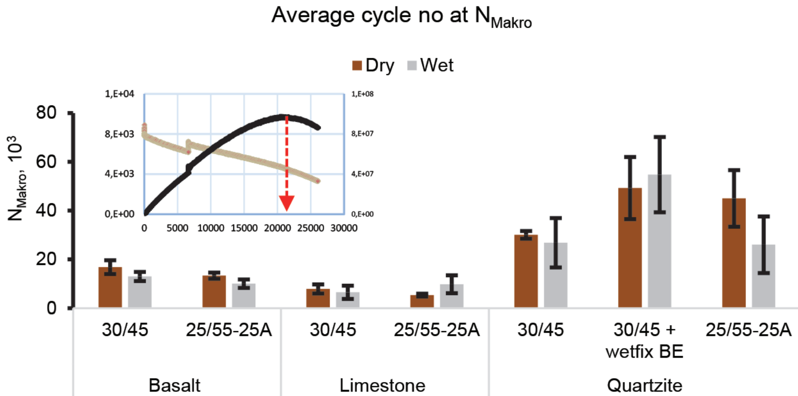

Figure 2 Cycle number at maximum N_{Makro}

The total number of cycles until failure N_{Makro} was used to compare the effect of moisture conditioned and the dry sample to fatigue resistance. Three specimens from each of the test group were considered, and the average number of cycles of each group was plotted as shown in Figure 2. Except for the samples made with limestone and 25/55-25A, and the quartzite aggregate with the application of Wetfix BE, moisture conditioned samples show less fatigue life at the compared to the dry samples. In general, the quartzite aggregate shows higher cycle life compared with limestone and basalt. The reason might be the percent bitumen binder used in quartzite aggregate (5.6 %) is higher than used in limestone (4.9 %) and basalt (4.9 %), which reached in a similar bitumen/aggregate volume fraction, however, didn't consider individual bitumen needs of the tested aggregates.

4 Conclusion

The effects of moisture in viscoelastic and mechanical behavior of asphalt mixture were studied using three sources of aggregate (Basalt, Limestone and Quartzite) and two bitumen binders (30-45 and 25/55-25A) using fatigue test procedures according to EN 12697-24, Annex 7. From the tests, following conclusion can be drawn. To investigate the effects of moisture in stiffness recovery properties of the asphalt mixture, a rest period 7500 sec inserted at 80 % of E^*_{ini} and the result indicated that moisture in the asphalt pavement reduced the self-healing effects of asphalt. The recovery properties rely on the viscoelastic nature of asphalt that highly depend on the bitumen binder. Hence, separate studies on the effects of moisture in the bitumen binder is crucial.
The limestone has relative advantages on resisting the effects of moisture. The results show that the stiffness modulus of moisture conditioned specimen is equivalent with the dry sample. Also, the fatigue life between the dry and wet specimens is comparative. This is the advantage of limestone, and it is not observed in basalt and quartzite aggregates. However, it is not reasonable to compare results between the three aggregates, because different bitumen content used in the mix and the variable aggregate gradation from the quarry site affects the mixture properties. The polymer modified bitumen binder, 25/55-25A has an advantage on recovering the stiffness modulus in all sample groups for both dry and wet specimens. Moreover, for the applied test temperature of 20 °C, it increases the fatigue life in dry samples of asphalt made with quartzite aggregate. However, it didn't show advantages to the fatigue life of moisture conditioned specimens. The applied surfactant additives show advantages to increase the bond between bitumen binder and aggregate. The results show that using 0.5 % of surfactant in the asphalt mix made with quartzite aggregate has advantages to improve the moisture resistance ability and increase the fatigue life of the pavement.

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