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THE EFFECT OF THE SILO-STORAGE ON THE RHEOLOGICAL BEHAVIOR OF A SURFACE COURSE ASPHALT MIX CONTAINING RECLAIMED ASPHALT PAVEMENT (RAP)

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Abstract: The extent of diffusion/blending between aged binder from reclaimed asphalt pavement (RAP) and virgin binder in asphalt mixtures could affect both the performance of the produced Hot Mix Asphalt (HMA) and the economic competitiveness of the recycling process. During the production process of HMA with RAP, it is generally understood that a partial blending occurs between aged and virgin binders. The degree of blending could be increased, and the blending could be reached to completion by increasing the time of silo storage after the mixing. Nevertheless, a limited number of studies have considered the time-temperature effects of the silo storage on the diffusion mechanism between virgin and RAP binders. In this paper, the kinetics of blending of aged and virgin binders are examined by considering the time-temperature effect of silo storage on the rheological properties of HMA containing RAP. HMA samples of an HL-3 mix designed with 15% RAP were collected after production from the asphalt plant at different silo-storage intervals (1, 4, 8, and 12 hours), with their temperature being closely monitored and recorded. The resulting mixes were compacted on-site, and their rheological properties were characterised using the Complex Modulus Test. The analysis of these results indicates that there is no significant change in the stiffness of the mixes in the silo storage time varied from 0 to 1 and 4 hours. Yet, there is a noticeable change in the rheology of the mix for 8 hours and 12 hours at the test temperatures above 4˚C. This change is directly associated with higher temperature and low frequencies of the complex modulus test. Therefore, silo storage time had an impact on the rheological behaviour at higher temperature and low frequencies during the test, which indicated a better blending of aged and virgin binders with higher storage time.

Keywords: HMA, RAP, Diffusion, Silo-storage, Complex Modulus Test, Master Curve.

1. INTRODUCTION

Reclaimed Asphalt Pavement (RAP) comes from the recovery of old pavements at the end of their service life. These pavements can be crushed and reused in new pavement. The RAP binder is a thin layer that coats RAP aggregates and does not exist as a free mass in the mixture. Therefore, mechanical blending may not be the most effective mode of mixing between the aged binder and virgin binder. The blending can be described using other phenomena which can help the two binders blend at proper temperatures for a required time (Kriz, D. L. Grant, et al.). This mechanism is called diffusion, which allows molecules transfer between materials when they have enough energy to move. As it is very important for this study identify the factors having an actual impact on the diffusion in RAP-containing mixes, comprehensive literature review has already been conducted in order to enhance the knowledge on RAP binder properties, rejuvenation of recycled binder, and the blending of aged and virgin binders through diffusion. From a literature study it appeared that two main factors have significant impacts on blending between aged and new binders in the asphalt mixture were time and temperature (Alavi et al., 2015; Kriz et al., 2014a, 2014b; Rad et al., 2014; Yousefi, 2013).

Some researchers (Baaj, Dorchies, et al.; Baaj, M. Ech, et al.; Baaj, Mohsen Ech, et al.; Baaj and Paradis; Tapsoba et al.) have studied the impact of asphalt recycled materials (Recycled Asphalt Pavement and Recycled Asphalt Shingles) on the Linear Visco-Elastic (LVE) behaviour and on the performance (fatigue cracking, rutting, low temperature cracking and moisture resistance) of asphalt mixtures. These studies showed the great potential of using recycled materials as both substitution material and mixture behaviour modifier. By analyzing the rheological behaviour of produced HMA, the authors concluded that the overall performance of RAP-modified mixes can have performance comparable to non-RAP mixes with up to 40% RAP substitution. Hence, mixes with RAP can provide more economical pavement designs using empirical or mechanistic pavement design methods. Other researchers have also used rejuvenating solutions to accelerate binder diffusion and enhance the blending (Baaj et al. 2014). In addition, the team of Prof. Susan Tighe at the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo have conducted several research projects (Ambaiowei, 2014; Sanchez et al., 2015, 2012; Sanchez and Tighe, 2015; Varamini et al., 2014; Yang et al., 2013) to establish a guideline on using RAP based on its performance assessments under local (Ontario) climate conditions. For example, the performance of laboratory-prepared Superpave SP12.5 mixtures with varying percentages of RAP contents were investigated by exposing the specimens to repetitive loading, low temperature cracking and rutting (Sanchez, 2014). Although these studies have shown the potential of using RAP with minimal negative impacts on the behavior of asphalt mixes upon rutting and fatigue, it appears that the low temperature cracking performance remains a major challenge. This can be attributed to insufficient (inefficient) blending between the aged RAP and virgin binders (Aurangzeb et al., 2012, Ma et al., 2010).

The researchers of Imperial Oil have also contributed to understanding of the blending phenomenon (Kriz, D. L. Grant, et al.). Their recent study showed that the diffusion between the in-contact layers of the aged and the virgin binders may explain the blending process. A significant part of the blending takes place during the mix production, storage and placement of the asphalt mix, but blending continues during road service due to diffusion.

As the time-temperature effect of silo-storage on RAP-containing HMA can optimise the blending between virgin and RAP binders, improving blending efficiency of RAP and virgin binders could potentially offer a solution to enhance the durability performance of RAP mixtures. Thus, this paper has examined the kinetics of blending of aged and virgin binders by considering the effect of silo storage on the rheological properties of HMA containing RAP.

2. MATERIALS AND METHODS

2.1 Sample Collection and Specimen Preparation

A surface course HL-3 Marshall mix (OPSS 1150) containing 15% RAP was collected from Miller Group asphalt plant in Markham, Ontario. This mix has a total of 5% asphalt binder (approximately 4.7% virgin binder and 0.3% RAP binder). The mixing temperature was 148˚C and the compaction temperature was 135˚C.

To investigate the time-temperature effect on the blending efficiency, samples were collected as a function of time mixture spent in silo. The first sampling was done immediately after production and then at several time intervals of silo-storage such as 1, 4, 8, and 12 hours. In order to avoid reheating the asphalt and inducing any bias in the temperature profile of the tested samples, the compaction was conducted using Superpave Gyratory Compactor immediately after the sampling at the quality control laboratory of the asphalt plant. The specimens were compacted at target air voids of 7 % ± 0.5 %, coming down to around 4% ± 0.5 % once the samples were cored. The compacted specimens were kept at temperature room to cool down and then transported to the University of Waterloo and stored in a conditional room at 5 ˚C until the day of testing to eliminate any further blending.

The compacted specimens were cur and cored to create triplicate Ø100×150H mm cylinder dynamic modulus specimens to be tested using the CPATT Material Testing System (MTS).

2.2 Dynamic Modulus Test Setup

The main objective of utilizing dynamic modulus test is to evaluate the HMA mixtures properties under different temperatures and frequencies and observe the effect of silo storage on their rheological behaviour. The test was performed according to the procedure given in AASHTO TP 62-07, Standard Test Method for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures. The test specimens will be subjected to a repetitive, compressive, and sinusoidal load. Two Linear Variable Differential Transducers (LVDTs) were used to measure the deformation of test specimen. Each specimen was examined at six loading frequencies (0.1, 0.5, 1.0, 5.0, 10.0 and 25 Hz) and seven temperatures (-10, 4, 21, 37, and 54 ˚C). For each temperature, the specimens are conditioned and then subjected to compression load at the six frequencies.

3. RESULTS AND ANALYSIS

Figure 1 below shows no significant change in the complex modulus values for the mixes that have been stored in the silo for 1 and 4 hours and those obtained for the mix collected without silo storage.

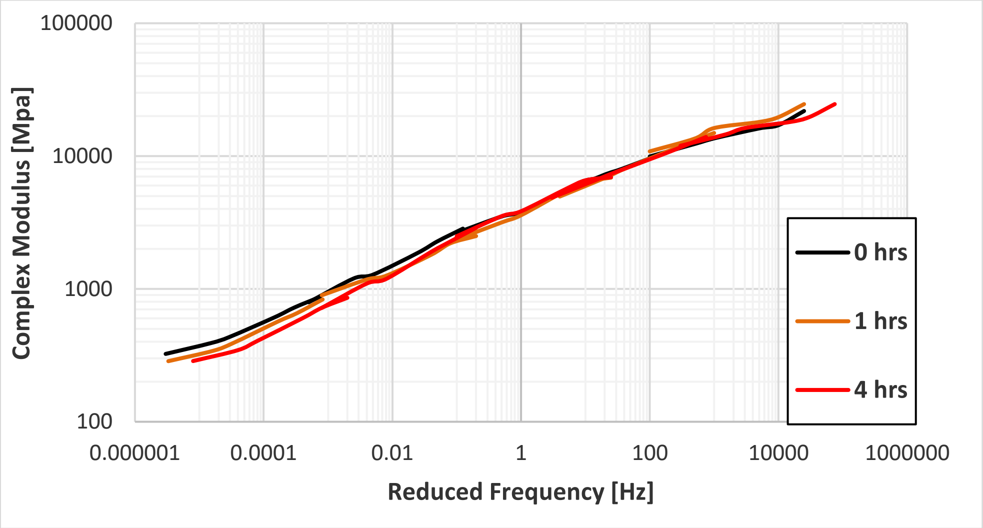

Figure 1: Master curve for 0, 1, 4 hours in the silo storage

As it is difficult to visualize the differences between the samples in the master curve, Figure 2 shows the differences between the stiffness values of the three mixes. Each ratio value represents the stiffness of the mix without silo storage (called E0) divided by the stiffness of the mix with 1 hours silo storage (E1) (right) and by the stiffness of the mix with 4 hours silo storage (E4) (left) for each temperature and frequency of loading. Figure 2 clearly shows that the ratio values do not exceed 1.15 in both cases, hence, there does not appear to be significant blending between aged and virgin binders of the mixes during the 4 hours of storage time.

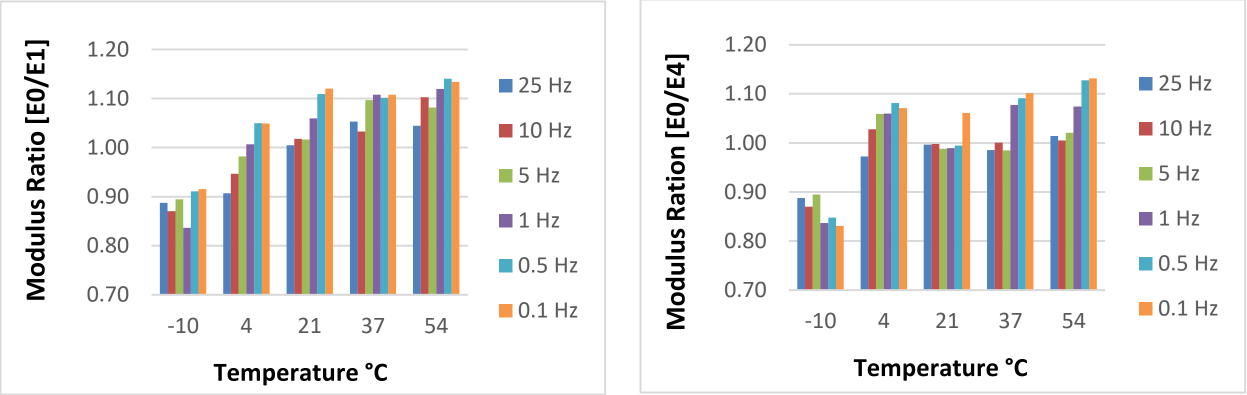

Figure 2: Modulus ratio values at different testing temperatures and frequencies (E0/E1) (left) and (E0/E4) (right).

However, the modulus values for the mix that has been stored in the silo for 8 hours are lower than those obtained for the mix collected without silo storage, as shown in the Master Curve in Figure 3.

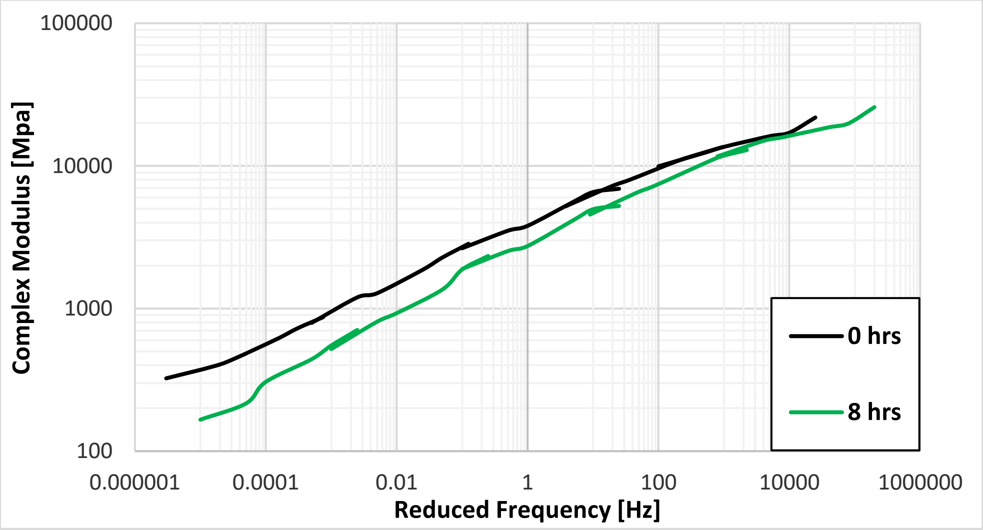

Figure 3: Master curve for 0 and 8 hours in the silo storage

The difference in stiffness is actually significant, but logarithmic presentation of Master Curves makes it difficult to visualize.

Figure 4 shows the ratios between the modulus values of the two mixes. Each ratio value represents the stiffness of the mix without silo storage (called E0) divided by the stiffness of the mix with 8 hours silo storage (E8) for each temperature and frequency of loading. The examination of these results indicate that the two mixes have similar stiffness values at low temperatures (-10℃ and 4℃) but the ratio values become progressively higher than 1 (up to 1.92) at higher temperatures and low frequencies, indicating that silo storage make the asphalt mix softer at high temperatures. This might also indicate that part of the aged binder in the mix became more active and mingled with the virgin binder when increasing the time of the mixture in the silo. It has been shown that increased binder blending can reduce the overall binder stiffness (Shirodkar et al.) This preliminary results show an interesting and promising trend.

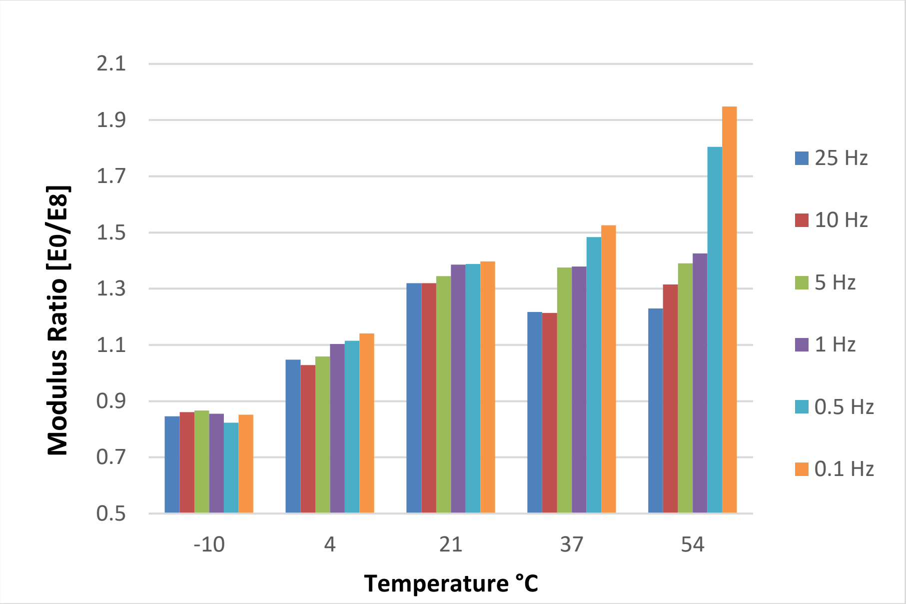

Figure 4: Modulus ratio values (E0/E8) at different testing temperatures and frequencies

As it has been demonstrated in Figure 5, both of the mixes that have been obtained at 8 and 12 hours in the silo storage have similar complex modulus values. However, there is a slight reduction in the stiffness for the 12-hour samples at the high temperatures.

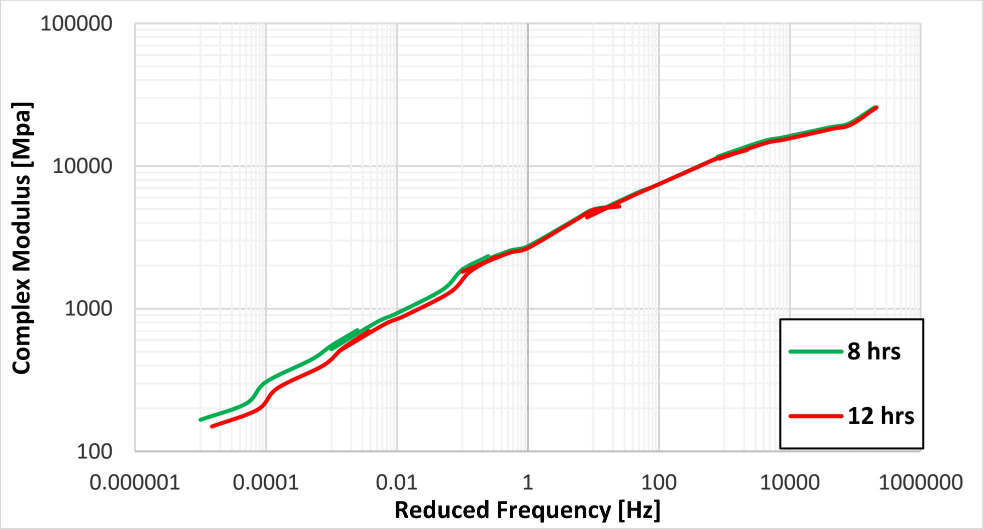

Figure 5: Master curve for 8 and 12 hours in the silo storage

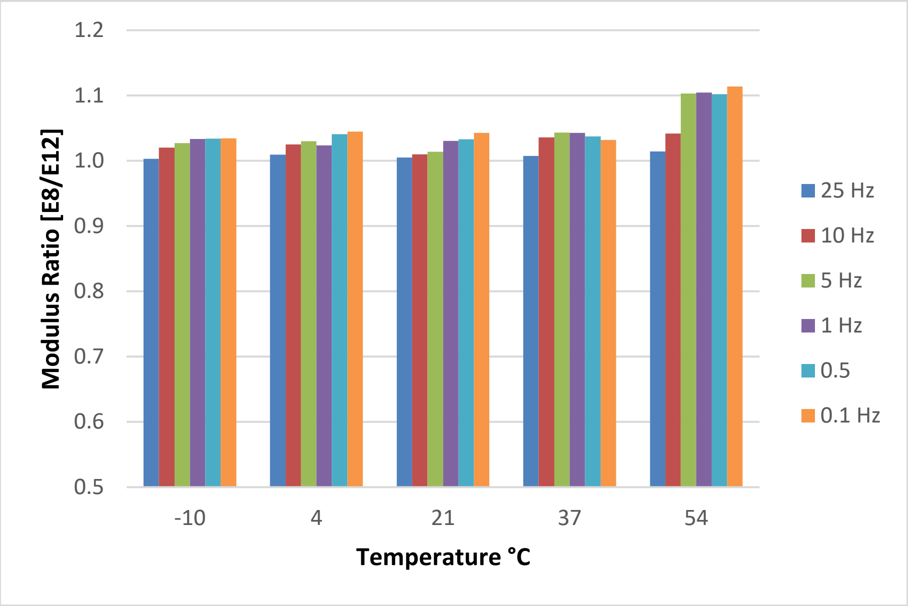

Figure 6: Modulus ratio values (E8/E12) at different testing temperatures and frequencies

CONCLUSIONS

The conclusions of the study of the effect of silo-storage on the rheological behavior of an HL-3 mix containing RAP are as follows:

1. There was no significant change in the complex modulus values for the samples that have been collected immediately after production and the ones collected after 1 and 4 hours. Hence, there is no considerable effect of 4 hours of silo storage on the rheology of the mixes.

2. A decrease in the stiffness was found for the samples that have been collected after 8 hours in the silo storage. This is likely due to an increase in the efficient binder content in the mixture due to increased overall blending. This would theoretically, result in an enhanced adhesion between the binder and the aggregates and would improve the quality of the HMA. However, further research is recommended to confirm this conclusion.

3. The change in rheology from the 8 hours samples to the 12 hours samples was barely noticeable at the temperatures below 54 ˚C. However, this partial conclusion may apply only in the case of this mix and silo storage conditions.

4. Finally, the test results indicate that the silo storage time had a strong impact on the rheological behaviour, and higher storage time would improve blending of RAP and virgin binders which would have a positive impact on the overall quality of HMA RAP mixtures.

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