Evaluating Permanent Deformation in Asphalt Mixes Containing Reclaimed Asphalt Pavement by Considering the Effect of Silo Storage Time

Hawraa Kadhim[1], Hassan Baaj[2], Payman Pirzadeh[3]
([1] University of Waterloo, 200 University Ave W, Waterloo, ON, h2kadhim@uwaterloo.ca)
([2] University of Waterloo, 200 University Ave W, Waterloo, ON, hbaaj@uwaterloo.ca)
([3] Sarnia Technology Applications & Research, Downstream and Chemical, Imperial, Sarnia, ON, Payman.Pirzadeh@esso.ca)

ABSTRACT

The use of Reclaimed Asphalt Pavement (RAP) in Hot Mix Asphalt (HMA) has been increasing in the last few decades due to cost benefits of using RAP and compelling need to preserve the environmental and natural resources. It is commonly assumed that HMA containing RAP has an improved resistance to permanent deformation (rutting) due to the fact that RAP binder is usually harder than virgin binder. However, during the production process of HMA with RAP, the blending between aged and virgin binders would be partial, which would create heterogeneity in distribution of the hard recycled binder and the soft virgin binder in the HMA-RAP mixes. This results in overall softer regions in the HMA-RAP mix than regular HMA and consequently a potential lower rutting performance of the mix. Thus, the purpose of this study is to evaluate the rutting resistance of the HMA containing RAP by considering the time-temperature effects of the silo storage on the blending mechanism between virgin and RAP binders. HMA samples of HL-3 and HL-8 mixes designed with 15% and 30% RAP, respectively, were collected after production at different silo-storage intervals (0, 1, 4, 8, and 12 hours) from an asphalt plant. Temperatures of collected mix samples were closely monitored and recorded. Results indicate that samples collected after 12 hours of silo storage exhibited a slight reduction in their average rutting depth accompanied with a reduction in their corresponding stiffness compared to those collected at 0 hours.

Keywords: Reclaimed Asphalt Pavement, Rutting, Silo-Storage, Stiffness, Asphalt Blending.

1 INTRODUCTION

Rutting is the progressive accumulation of permanent deformation in each layer of pavement structure due to repetitive loading (1). It is the primary concern in locations with high in-service temperatures (above 38°C) and heavy traffic loads (2). HMA containing RAP typically has enhanced rutting resistance (3). Laboratory Wheel-Tracking Devices are often employed to run simulative tests to evaluate HMA rutting performance. This evaluation is usually performed by rolling small loaded metal or rubber wheels over the surface of asphalt samples (4) for several thousands of cycles and the performance is compared to actual in-service pavement performance.

As the diffusion is a slow blending mechanism, understanding the nature of blending between RAP and virgin binder was presumed by some researchers (5). They stated that HMA RAP are more likely to have regions that are more susceptible to the rutting in the mixture. Incomplete blending would result in a mix with lower rutting resistance as compared to the regular HMA (5).

Literature indicate that two factors can particularly have significant impacts on blending process between aged and new binders in HMA-RAP: time and temperature (6). The silo used for storing HMA is a place where these two factors are in play. Consequently, improving blending efficiency of virgin and RAP binders could potentially offer a solution to enhance rutting resistance of the HMA-RAP mixes, and thus enhance the durability.

The researchers of Imperial Oil have contributed to the understanding of the blending phenomenon (7). Furthermore, it has been argued that extending the duration of silo-storage may result in a more homogeneously blended binder within a few hours; yet, it might make the binder susceptible to aging during storage (7). Therefore, it is necessary to determine the suitable storage duration to accelerate the diffusion and enhance binder blending in HMA-RAP mixes without causing significant aging to the (virgin) binder (8).

2 EXPERIMENTAL PROGRAM AND PROCEDURES

Marshall mixes of a surface course HL-3 containing 15% RAP and base course HL-8 containing 30% RAP were collected from a Miller Group asphalt plant in Markham, Ontario. HL-3 mix has a total of 5% asphalt binder (approximately 4.4% virgin binder and 0.6% RAP binder). On the other hand, HL-8 mix has a total of 4.7% asphalt binder (approximately 3.5% virgin binder and 1.2% RAP binder). To investigate the time-temperature effect on blending efficiency, the samples were collected as a function of storage time in the silo. The first sampling was done immediately after production (t = 0 hour), and then at several time intervals of silo-storage at 1, 4, 8, and 12 hours. A portion of mixes were immediately compacted using Superpave Gyratory Compactor at the asphalt plant. The compacted and loose mixtures were then transported to the University of Waterloo in a refrigerated truck and kept in a storage room at 7 ˚C until the day of testing. Keeping samples at low temperatures helps avoiding additional binder diffusion during the storage.

Triplicate Ø100×150H mm cylinder dynamic modulus specimens were prepared for each silo time. The samples were tested at the Centre for Pavement and Transportation Technology (CPATT) using the Material Testing System (MTS) press equipped with an environment chamber. The test was performed according to the procedure given in AASHTO TP 62 (9). The Hamburg Wheel-Track Device (HWTD) test was carried out according to AASHTO T 324 (10). Quadruplicate Ø150×63H mm cylinder specimens were created for each silo time with 7 ± 0.5 % air content for rutting test. The specimens were tested in wet condition at 50˚C by using hard rubber wheels. Linear Variable Differential Transducers (LVDT) were used to measure the depth of the impression of the wheel (rutting depth).

3 EXPERIMENTAL RESULTS AND ANALYSES

3.1 Complex Modulus Test Results

The averaged HL-3 master curve for each silo time indicates that complex modulus of HL-3 samples collected between 0 and 4 hours do not differ significantly (FIGURE 1-A). However, a noticeable change is observed in the stiffness of mix samples collected after 8 hours of silo storage, particularly at higher temperatures (low reduced frequencies).

As it is difficult to visualize the differences between the samples in the log-log master curve, FIGURE 2, 3, 4, and 5 represent the differences ratio values of the five mixes. Each ratio value represents the stiffness of the mix without silo storage (called E0) divided by the stiffness of the mix with 1, 4, 8, and 12 hours silo storage (called E1, E4, E8, and E12, respectively).

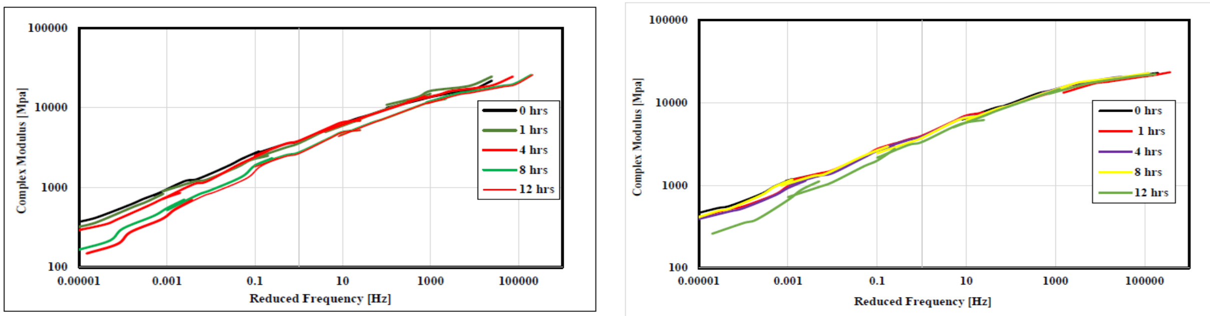

FIGURE 1 Master Curves for the HL-3 (A) and HL-8 (B) Mixes at 0, 1, 4, 8, and 12 Hours of Silo Storage

The modulus ratio (E0/E1) and (E0/E4) did not exceed 1.15 in case of HL-3 as shown in FIGURE 2 and 3. While the complex modulus value for 0 hours storage is two times higher than that of 8 hours and 12 hours in the silo storage as shown in FIGURE 4 and 5, respectively. The modulus ratio values in both cases (E0/E8) and (E0/E12) reach 2.2 (22).

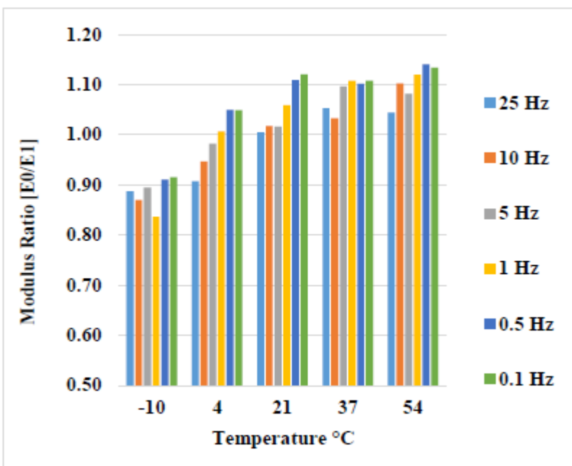

FIGURE 2 HL-3 Modulus Ratio Values (E0/E1)

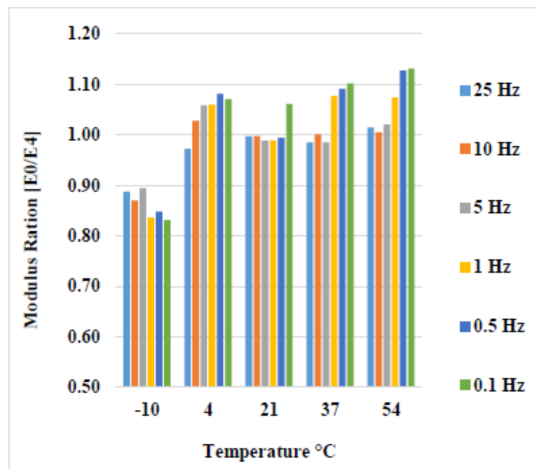

FIGURE 3 HL-3 Modulus Ratio Values (E0/E4)

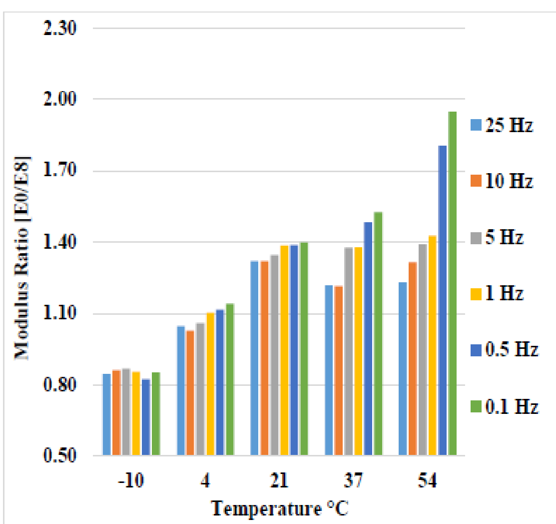

FIGURE 4 HL-3 Modulus Ratio Values (E0/E8)

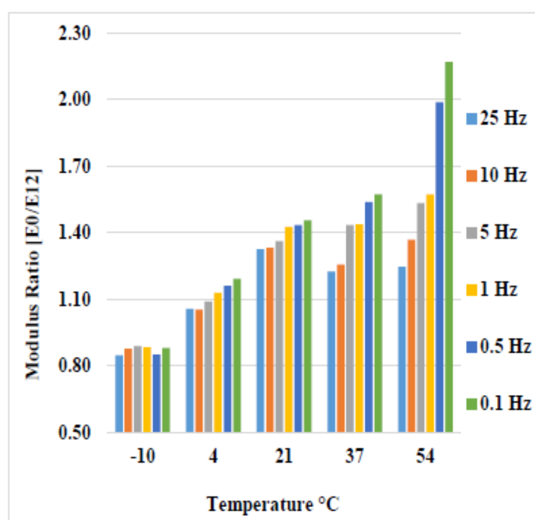

FIGURE 5 HL-3 Modulus Ratio Values (E0/E12)

On the other hand, there is no notable changes in the stiffness of HL-8 mixes up to 8 hours in the silo storage, and the significant reduction in the stiffness is only observed for the 12 hours samples as illustrated in the master curve FIGURE 1-B above.

3.2 Rutting Test Results

Despite the fact that the specimens with 12-hrs silo storage for both HL-3 and HL-8 have lower complex modules than 0-hrs at higher temperatures, the results indicate that the 12-hrs specimens tend to exhibit a slightly improved resistance to rutting as shown in FIGURE 8.

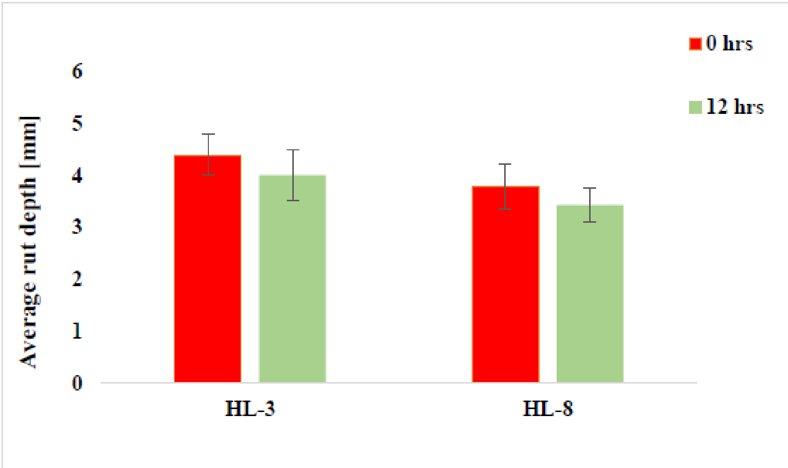

FIGURE 8 Comparison of the Rutting Results of HL-3 and HL-8 at 0 and 12 Hours after 10,000 Cycles

The reason behind this improvement might be related to the fact that a better blending between the aged and the virgin binder happened after 12 hours storage at high temperature (approximately 148 ˚C). Hence, the data suggest a trend toward an increase in rutting resistance with 12-hrs of silo storage for both HL-3 and HL-8 mixes. Test results of Hamburg rutting test for both HMA mixtures are presented graphically in FIGURE 9.

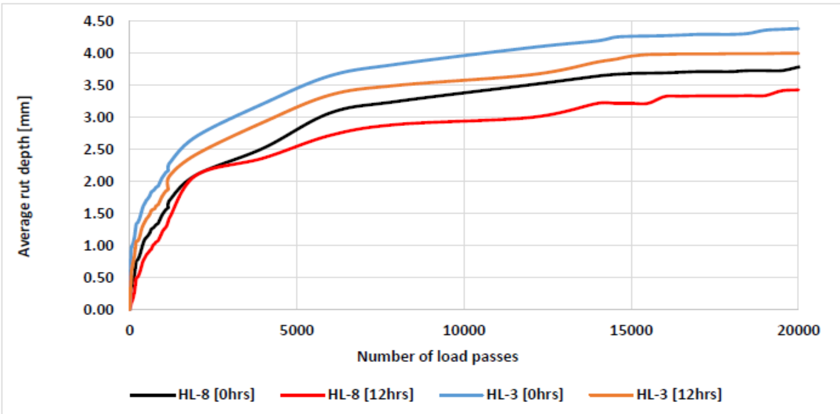

FIGURE 9 Hamburg Rutting Results for HL-3 and HL-8 Mixtures after 10,000 Cycles

4 DISCUSSION OF RESULTS AND CONCLUSIONS

The main objective of this paper was to investigate the rutting performance of asphalt mixtures containing RAP by considering the silo storage time using HWTD. The complex modulus test was utilized to examine the time-temperature effect of the silo storage on the rheological behaviour of the HMA RAP mixtures.

For the HL-3 mixtures, there was no significant change in the complex modulus values of samples that were collected at 0, 1 and 4 hours of silo storage. Hence, this would indicate that there was no considerable effect of a 4 hour silo storage on the rheology of this mixture. On the other hand, a decrease in the stiffness at high temperatures/lower frequencies was observed in the HL-3 samples collected after 8 hours of silo storage. The change in rheology for HL-3 from the 8 hours sample to the 12 hours sample was barely noticeable at temperatures below 54 ˚C. In contrast, the change in the rheology for HL-8 mixture was only present in samples stored for 12 hours. Theoretically, more blending would result in an enhanced adhesion between the binder and the aggregates and would improve the quality of the HMA and enhance resistance to permanent deformation. This is more likely because the RAP binder had an increased contribution to the efficient asphalt binder used within the mixture due to increased overall blending. However, further research is recommended to confirm this conclusion.

The results of the HWTD test appear to point that the rutting resistance of the HL-8 mixtures was slightly better than that of the HL-3 mixtures. This is because the RAP content in HL-8 mixture is higher than the one in HL-3 resulting in a stiffer overall mixture; hence, providing a better shear resistance to the mixture. In addition, HL-8 mixtures had a lower asphalt binder content and larger nominal maximum aggregate size (NMAS) that provides an overall smaller surface area to be coated by the asphalt binder. This resulted in a better adhesion of HL-8 mixtures in comparison to the HL-3 mixtures. Moreover, HL-8 had a softer virgin binder (PG52-34) compared to HL-3 which had (PG58-28). This might help more softening of RAP and better adhesion of the mix. Overall, the results of the HWTD test shows a trend toward an increase in rutting resistance with 12-hrs of silo storage for both HL-3 and HL-8 mixes. More blending provides more effective binder in the mixtures; therefore, more adhesion between the binder and the aggregate was obtained.

Finally, data suggest that the silo storage time can have impacts on the rheological behavior of the HMA. Therefore, higher storage time, 12-hrs for the given mixes and silo conditions (temperature & no access of air), could potentially improve the blending of RAP and virgin binders which slightly impacts the rutting performance of HMA-RAP mixtures. Despite the fact that the rutting resistance has improved by only 1.1 time for the 12-hrs samples as compared with the 0- hrs samples, these results are promising and suggest more samples to be analyzed and investigated to draw more solid conclusions.

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