Interim Report on Pilot Study

for the use of Lime Prills in lieu of Hydrated Lime Powder

Summary

The objective of this study was to determine whether or not lime prills can be used as a substitute for hydrated lime in asphalt mixes and achieve the same degree of benefit as that achieved with hydrated lime. In this study a Dynamic Mechanical Analyzer (DMA) was used to measure the fatigue cracking characteristics of a fine aggregate asphalt matrix (asphalt binder + mineral filler + aggregates passing sieve #16) for six different mixes using two different binders (AAB and ABD) and three different treatments (no lime, hydrated lime, and lime prills). Two parameters from the DMA tests were used to characterize damage in the asphalt matrix: fatigue life of the matrix and Cumulative Dissipated Pseudo Strain Energy (CDPSE) required to cause failure of the matrix. A higher value of these parameters indicates a superior matrix response under cyclic loading. Tests on the matrix comprised of asphalt binder AAB and gravel aggregate shows that addition of hydrated lime and lime prills significantly improved the fatigue cracking characteristics of the matrix. Furthermore, there was no significant difference when performance of the matrix with hydrated lime was compared with the performance of the matrix with lime prills. However, tests with asphalt binder ABD demonstrated that neither hydrated lime nor lime prills significantly changed the performance compared to the control matrix with normal filler (no hydrated lime). This was in part because of the limited reactivity between the asphalt binder ABD and hydrated lime. In fact this binder was selected as we knew it was not reactive with hydrated lime based on surface energy measurements and chemical analysis.

Introduction

Addition of hydrated lime to hot mix asphalt results in multiple benefits such as improved resistance to plastic deformation, moisture damage, and fatigue cracking. Several mechanisms that explain the chemically active interactions of hydrated lime with the asphalt binder and its potential benefits to as a filler for hot mix asphalt are discussed in the literature. Perhaps the best single review of these multifunctional advantages is by Little and Petersen, 2005.. Commonly used methods of adding hydrated lime to asphalt mixes include adding the dry hydrate to damp aggregate in a pubmill mixing operation, adding lime slurry to aggregate in a pugmill and then allowing the lime treated aggregate to marinate or cure for a period of time before use, adding the hydrated lime into the drum just before adding the liquid asphalt, and adding lime directly into the pugmill of a batch plant. Although not presently a common method of addition, the blending of hydrated lime directly into the asphalt cement before the cement is added to the mixture offers some compelling benefits including improvement of the rheology of the mastic and the ability to interact more directly with carboxylic acids in the bitumen.

The objective of this study was to investigate whether or not hydrated lime can be added to asphalt mixes in the form of prills and achieve the same benefits as with the hydrated lime. This interim report describes some of the tests that were conducted to evaluate this objective. The performance of asphalt matrices with and without the addition of hydrated lime was evaluated using the Dynamic Mechanical Analyzer (DMA).

Materials

A total of six different types of asphalt matrices were investigated in this study. These matrices were comprised of two different types of asphalt binders (AAB and ABD), gravel aggregate, and three different types of treatment (no active filler, hydrated lime, and lime prills). The matrix is comprised of asphalt binders and fine aggregates that pass #16 sieve.

Typically, the percentage of fines (passing #200 sieve) added in an aggregate blend for hot mix asphalts ranges from 4 to 6%. When hydrated lime is added to the mix,

hydrated lime replaces approximately 1 to 1.5% of this filler by weight of the entire mix Following this standard approach, 30% by weight of the filler in these matrices (material passing #200 sieve) was replaced by hydrated lime or by prilles in selected matrices. It is important to highlight that when lime prills were added to the matrices (30% of the mineral filler was replaced by prills), we assumed that this represented a one-to-one substitute or comparison with hydrated lime. Three different types of prills were available for this study (Table 1). DMA testing has been completed on the Type 3 prills. Testing is still underway for Type I and II prills. According to the data we received, the active ingredients in all prills is $Ca(OH)_2$ and MgO and the only difference is the material used to bind the lime and MgO.

Table 1. Types and Description of Lime Prills.

Type	Binder	Process	Remarks
Type 1	75% Tall Oil and 25% Denatured Alcohol	Air Dried	Hydrated Lime with 5% MGO using DP-14 Pelletizer Disc.
Type 2	50% Norlig GI and 50% Water	Oven Dried	
Type 3	Tall Oil	Air Dried	

Sample Preparation

As previously described, the asphalt matrixes were comprised of the asphalt binder mixed with fine aggregate (passing sieve No.16). Figure 1 illustrates the gradation of fine aggregates for all matrix samples. As described previously, 30% of the fines were replaced with hydrated or lime prills for the corresponding mixes.

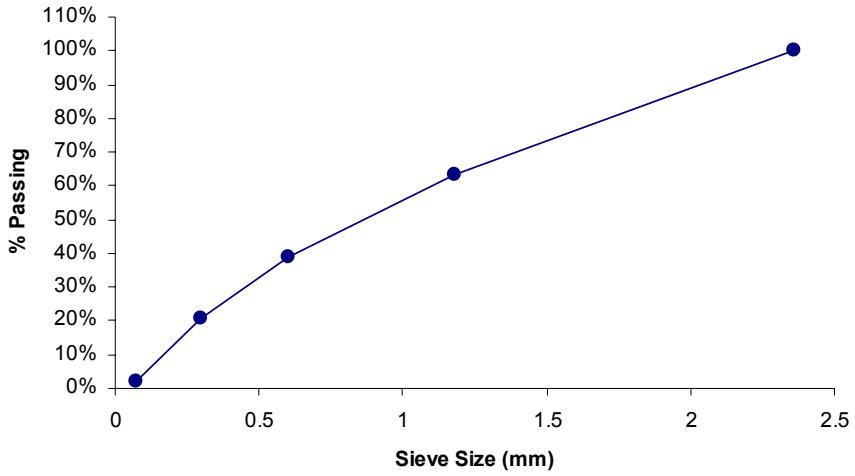

Figure 1. Gradation of Aggregates for the Mastic Sample.

The procedure followed to prepare specimen for testing with the DMA is very similar to the procedure followed for preparing asphalt mixes[1]. The percentage of asphalt binder was set to 8.9% by weight of the mix based on a procedure by Kim et al., 2003. The aggregates and the binder were mixed at the appropriate mixing and compaction temperatures using a mechanical mixer. The loose mixture was placed in a convection oven for two hours at the compaction temperature for short term aging. After aging the mix was compacted using a 152 mm diameter mold in the SGC to a height of 75 mm and target air void content of 13%.

The samples were allowed to cool to room temperature. Each side of the specimen (top and bottom) was trimmed to obtain a sample height of 50 mm. Approximately 30 specimens of 12 mm were obtained by coring 152 mm compacted sample (figure 2). The 12 mm mastic samples were labeled according to their position in the main sample (figure 3) in order to ensure that there is no excessive variability in air voids due to their location. The maximum specific gravity of the loose mix, bulk specific gravity of the samples, and the actual air void content of each 12 mm sample was determined in a manner similar to the asphalt mixes. The air void content of the samples was between 12.5 to 16 %.

Figure 2. SGC Compacted Sample and 12 mm Sample for DMA Testing.

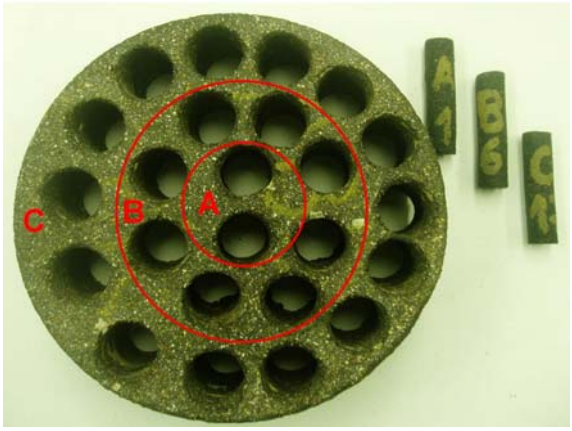

Figure 3. The three regions in the 152mm sample.

Tests and Analysis

The DMA test is conducted by fixing the lower end of the mastic sample and applying a strain or stress controlled torque at the top end of the sample and measuring the stress or strain response. Figure 4 illustrates the DMA test setup. When used with cyclic load tests, the shear modulus, G*, and phase angle, ϕ, at different load cycles are recorded by the software accompanying the DMA device.

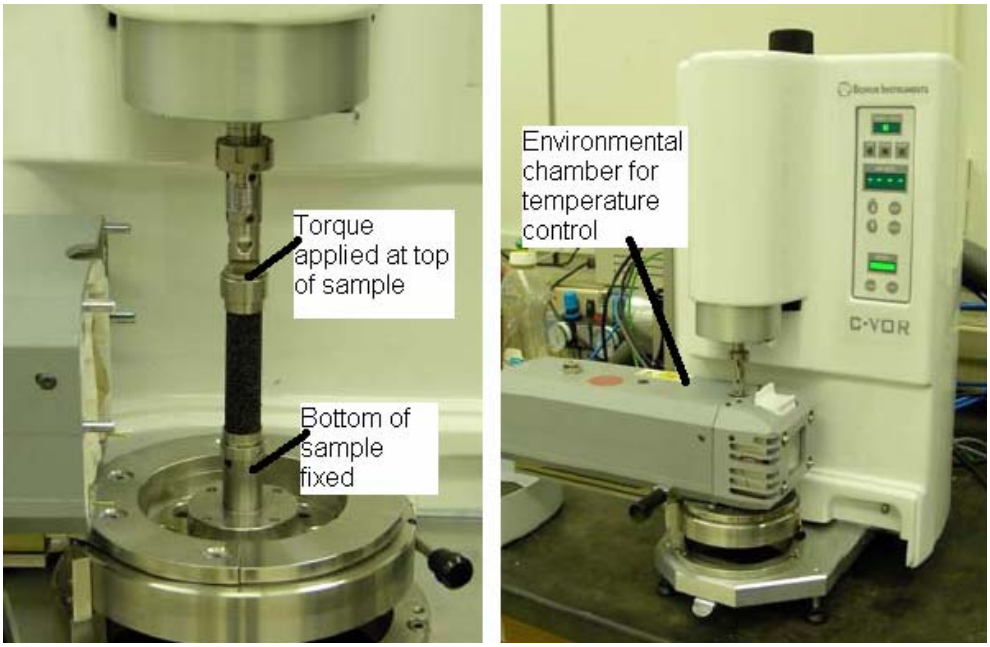

Figure 4. Sample and Test Setup for DMA.

Two types of tests were conducted with the DMA to obtain the necessary inputs to measure the fatigue cracking characteristics of the mix. The first type of test was a strain controlled cyclic load test conducted by applying a small strain of 0.0065% in a sinusoidal wave form at 10Hz frequency for approximately 500 cycles to obtain the undamaged reference modulus and phase angle of the material. The second test was conducted by applying a larger strain of 0.2% in a sinusoidal wave form at 10Hz frequency until the sample failed. Results from both these tests were combined for each sample to obtain the cumulative dissipated pseudo strain energy (CDPSE) and fatigue life of the mastic.

The fatigue life of the mastic sample was measured using the following parameter:

$$N\frac{G_N^*}{G_1^*} \qquad \textbf{(1)}$$

where, N is the number of load cycles, G_N^* is the shear modulus at the Nth load cycle, and G_1^* is the shear modulus at the 1st load cycle. Figure 5 illustrates a typical response curve that is obtained from the data with the DMA test.

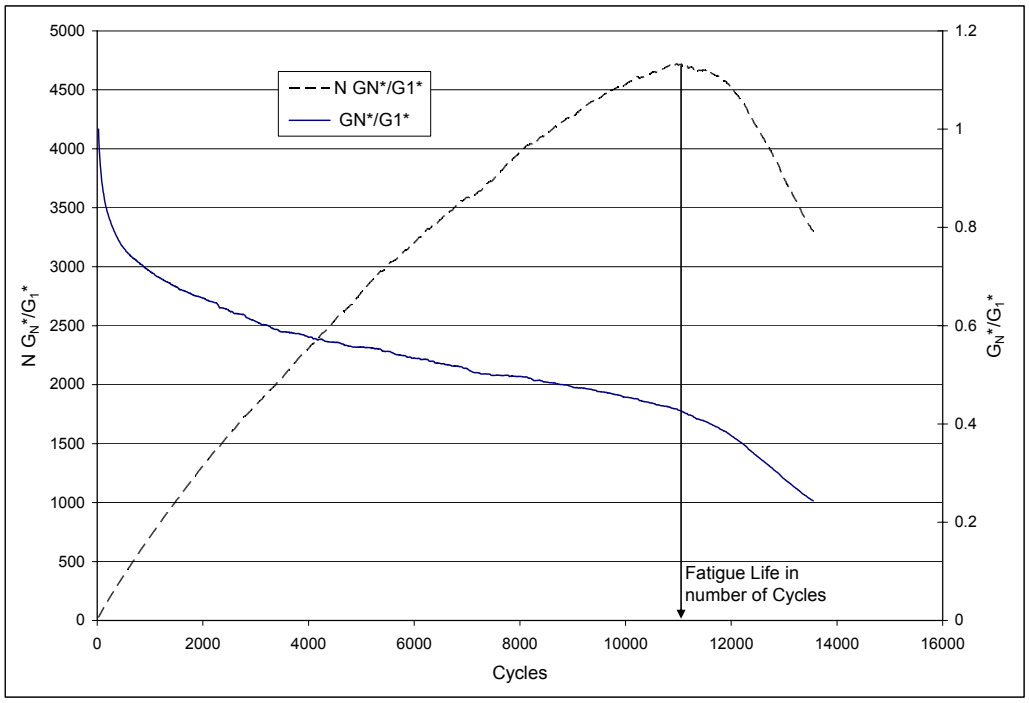

Figure 5. Typical Response Curve from DMA Test.

Hysteresis in the stress – strain curve for a given load cycle is a measure of the dissipated energy due to damage for perfectly elastic materials. However, for visco-elastic materials, a significant part of the hysteresis is due to the visco-elastic nature of the material, which causes it to recover or relax over a period of time. For these materials, the dissipated energy due to damage may be quantified by eliminating the effect of time dependent recovery or relaxation from the total hysteresis. One method for doing this is to measure the hysteresis from a stress – pseudo strain curve in lieu of a stress – strain curve. Figure 6 illustrates the difference between the dissipated strain energy due to viscoelasticity (area in the stress-strain loop) and the corrected dissipated pseudo strain energy (negligible area in the stress- pseudo strain loop) for an undamaged material. After correction for the viscoelasticity, the dissipated energy measured in the area of the stress-pseudo strain loop is referred to as the dissipated pseudo strain energy (DPSE) due to damage. In a strain controlled test, the DPSE decreases as the test progresses and the sample accumulates more and more damage. Figure 7 illustrates the typical decrease in the DPSE as the test progresses. Although the DPSE is measured at several intervals as the test progresses, only four curves are shown in this figure for

clarity. The DPSE is used to determine the cumulative dissipated pseudo strain energy (CDPSE) for the life of the mix. A matrix sample with higher CDPSE has better resistance to fatigue cracking.

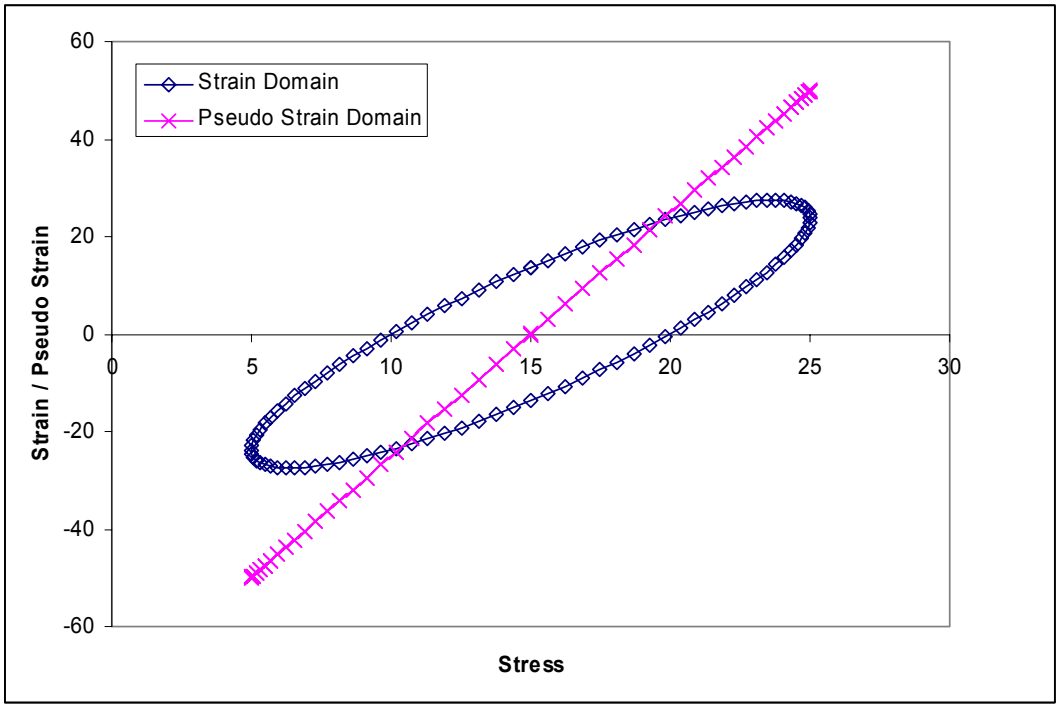

Figure 6. Comparison of stress-strain and stress-pseudo strain curve for an undamaged material.

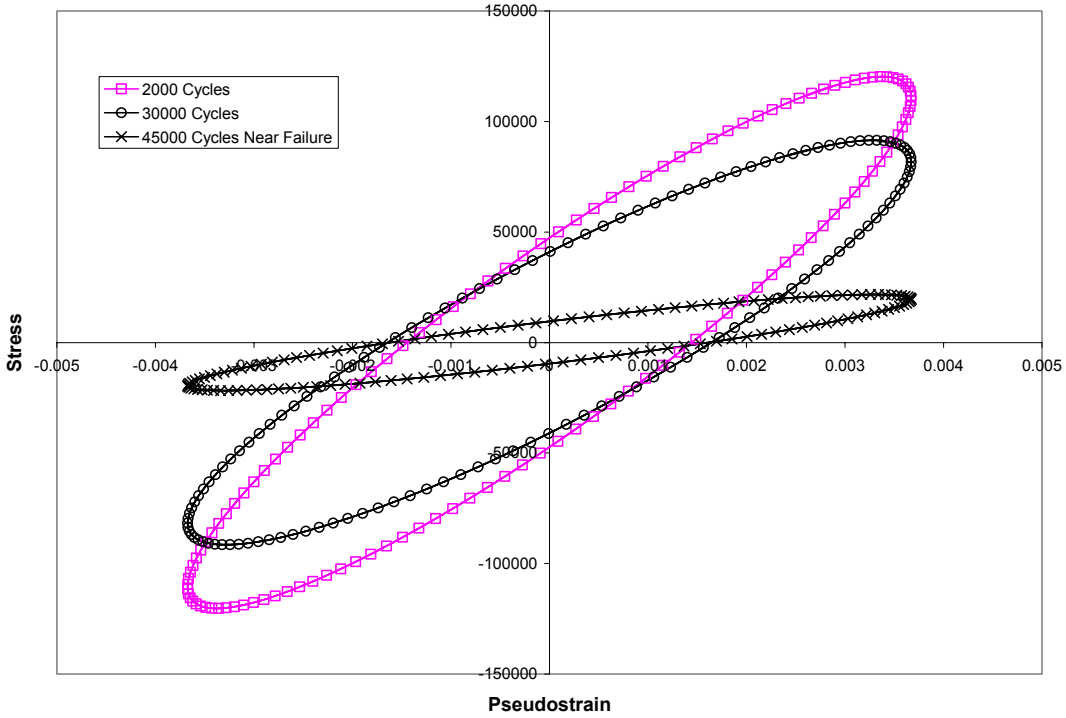

Figure 7. DPSE as a controlled strain test progresses.

Results and Discussion.

Three different comparisons among neat, hydrated lime, and lime prill mixes were of interest. The first was to determine whether performance of matrices mixes with hydrated lime was different from the performance of matrices with the lime prills. The second was to determine whether the addition of either hydrated lime or prills significantly improved the damage resistance of the matrices. Table 2 compares the two parameters obtained for the six mixes or matrices using the DMA. It is important to note that from 4 to 8 replicates were used for each mix or matrix type. Since the standard deviation of the results obtained was high, a more rigorous statistical comparison was made among these mixes. Table 3 presents a summary of the results from the hypothesis testing using the test data.

Table 1. Fatigue Life and CDPSE of Mastic Samples.

Binder and Parameter		Neat		Hydrated Lime		Lime Prills	
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
AAB	Fatigue Life ($x10^3$ cycles)	6.3	4.9	12.4	5.3	16.7	8.7
	CDPSE ($x10^6$)	11.9	8.8	50.9	24.7	51.7	34.5
ABD	Fatigue Life ($x10^3$ cycles)	5.7	1.0	3.1	0.4	2.2	0.4
	CDPSE ($x10^6$)	12.2	5.5	14.6	5.1	9.4	4.2

Table 2. Hypothesis Tests to Evaluate Effect of Prills.

Asphalt Binder	H_0	Neat Mix = Hydrated Lime Mix		Neat Mix = Lime Prill Mix		Hydrated Lime Mix = Lime Prill Mix	
	H_a	Neat Mix < Hydrated Lime Mix		Neat Mix < Lime Prill Mix		Hydrated Lime Mix ≠ Lime Prill Mix	
	Param-eter	p-value	Reject H_0 for H_a	p-value	Reject H_0 for H_a	p-value	Reject H_0 for H_a
AAB	Fatigue	0.040	Yes	0.016	Yes	0.284	No
	CDPSE	0.015	Yes	0.027	Yes	0.959	No
ABD	Fatigue	0.499	No	0.499	No	0.001	Yes
	CDPSE	0.216	No	0.337	No	0.048	Yes

From the statistical analysis the following conclusions are drawn:

- For asphalt AAB, both hydrated lime and lime prills significantly improved the performance of the mix.
- Also, for asphalt AAB, there was no significant difference in the performance of the hydrated lime mix as compared to the lime prills mix.
- For the asphalt ABD, addition of hydrated lime or lime prills did not significantly improve the performance of the mix as compared to the neat mix. Also, the mix

with lime prills had different performance as compared to the mix with hydrated lime.

One of the reasons for the peculiar behavior of ABD can be explained based on surface energy measurements on this binder performed in an earlier study. The surface energy component of asphalt binders is an important material property that influences the crack growth characteristics within the mix and also the adhesion with aggregates. When hydrated lime was added to ABD the Lifhsitz-van der Waals component of this binder did not change significantly (from 32.5 to 31.7 ergs/cm^2), where as when hydrated lime was added to AAB its Lifhsitz-van der Waals component increased significantly (from 13.6 to 23.8 ergs/cm^2). The acid component of surface energy decreased for both binders in relatively the same proportion and the base component of ABD increased significantly (from 0 to 2.7 ergs/cm^2). Although, surface energy of asphalt binder is not the sole parameter that influences the fatigue cracking characteristics of the asphalt mastics, it is important to see that different binders interact differently with hydrated lime.

In this study, hydrated lime and lime prills were added by substituting the 30% of the fines in the mastic (passing #200 sieve) by weight with equivalent quantity of hydrated lime powder or prill. It is speculated that in case of ABD, the hydrated lime was more functional as a filler with limited benefits from chemical activity with the asphalt binder and therefore there was no significant difference in the fatigue life as compared to the neat mix. Also, when prills were used with ABD, it is possible that the limited activity of lime from the prills prevented the proper breaking and dissolution of the prills in the mastic mix, thereby reducing the effective amount of fines in the mastic.

Further Testing

Testing is currently underway with asphalt AAD, which has proven to be very reactive with hydrated lime. Testing is also underway with Type 1 and Type 2 prills. This testing will be completed by April 7, 2006..

References

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Little, D. N., and Petersen, C., *"Unique Effects of Hydrated Lime Filler on the Performance-Related Properties of Asphalt Cements: Physical and Chemical Reactions Revisited",* Journal of Materials in Civil Engineering, Vol. 17, No. 2, 2005.

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