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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 different mixes with and without hydrated lime or 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 fail the matrix. A higher value of these parameters indicates a superior matrix response under cyclic loading because such a matrix can absorb more damage before it fails. Qualitative examination of the samples compacted using the three different types of prills indicates that the relative breakdown and dispersion of the prills in the asphalt binder differed depending on the type of prill.

Tests on the matrix comprised of asphalt binder AAD and gravel aggregate shows that the substitution of a portion of the fines (material passing #200 sieve) with hydrated lime or lime prills (using each of the three types of prills) increased the average fatigue cracking life and CDPSE of the matrix. This increase was statistically significant ($\alpha = 0.05$) for hydrated lime and two of the three types of prills. Furthermore, there was no significant difference ($\alpha = 0.05$) when performance of the matrix with hydrated lime was compared with the performance of the matrix with lime prills. Similar results were obtained with the asphalt binder AAB (tested with only one type of prill).

However, tests with asphalt binder ABD demonstrated that neither hydrated lime nor lime prills (tested with only one type of prill) 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 to assess the impact of magnesium oxide in the prills in isolation 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 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 pugmill 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 lime prills and achieve the same benefits as with the hydrated lime. This 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

Three different types of lime prills were available for this study (Table 1). 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 that is 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	

A total of eleven different types of asphalt matrices were investigated in this study. The asphalt matrices comprised of asphalt binder and fine aggregates that passed #16 sieve. Table 2 presents the combinations of materials and modifiers used in these eleven matrices.

Table 2. Asphalt Matrices Selected for Mechanical Testing with the DMA.

Binder-Aggregate fines	Modifier				
AAB-Gravel	None (Neat)	Hydrated Lime	Lime Prills (Type 1)	--	--
ABD-Gravel	None (Neat)	Hydrated Lime	Lime Prills (Type 1)	--	--
AAD-Gravel	None (Neat)	Hydrated Lime	Lime Prills (Type 1)	Lime Prills (Type 2)	Lime Prills (Type 3)

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 was added to the mix, it was used to replace 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 lime prills for the modified mixes. 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 substitution for hydrated lime.

Sample Preparation

As previously described, the asphalt matrices 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 modified mixes.

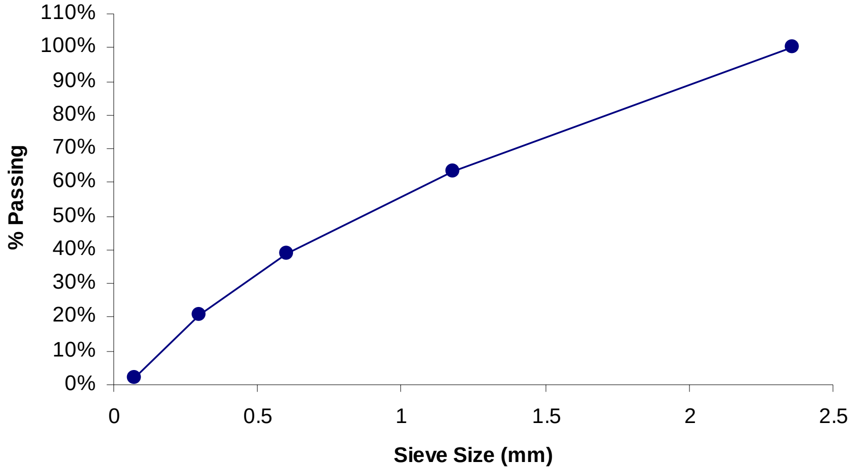

Figure 1. Gradation of Aggregates for the Mastic Sample.

The procedure followed to prepare specimen for testing with the DMA is very similar to the procedure followed for preparing asphalt mixes (Zollinger, 2005). 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. Oven dried hydrated lime or lime prills were added along with the asphalt binder prior to mixing. 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.

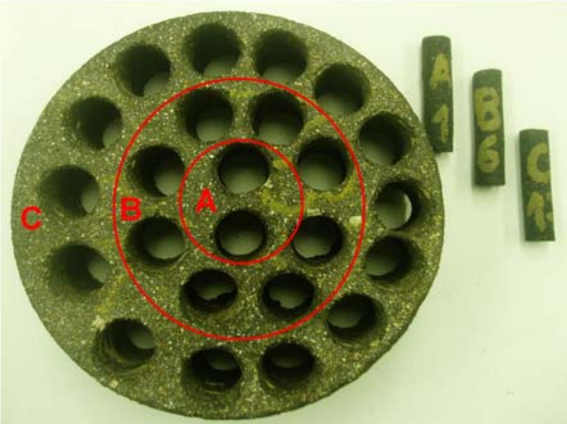

Figure 3. The three regions in the 152mm sample.

Figures 4 through 6 illustrate the sawed ends of the three asphalt matrices using binder AAD with the three different types of prills. Type 1 prills appear to have better breakdown and dispersion in the asphalt matrix compared to the other two types of prills. Although the dispersion of prills was not 100 % in all cases, the benefits in fatigue cracking life of the mix were still evident from the results with the DMA. Another notable feature about the residual prills after mixing and compaction was that these were relatively less friable due to sorption of asphalt binder as compared to the dry prills.

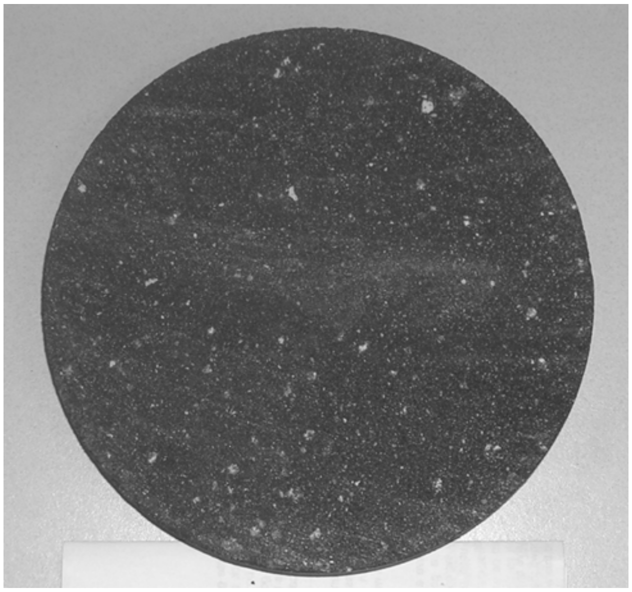

Figure 4. Type 1 Prills in AAD-Gravel Matrix.

Figure 5. Type 2 Prills in AAD-Gravel Matrix.

Figure 6. Type 3 Prills in AAD-Gravel Matrix.

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.

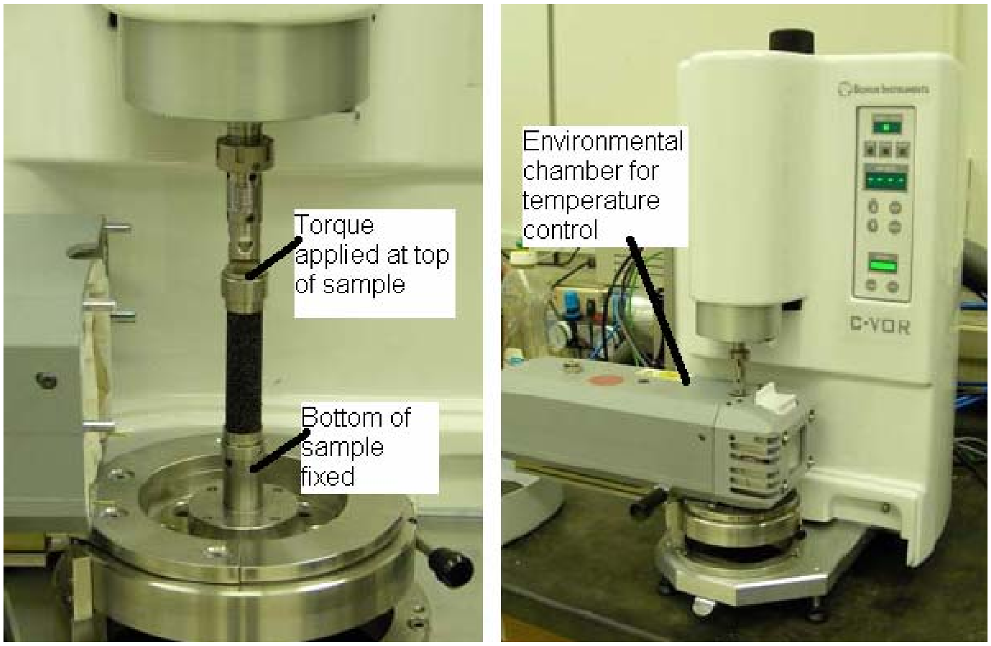

Figure 4. Sample and Test Setup for DMA.

Two types of tests were conducted with the DMA to obtain the necessary data 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:

$$N \frac{G_N^*}{G_1^*} \tag{1}$$

where, N is the number of load cycles, G_N^* is the shear modulus at the N^th^ 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.

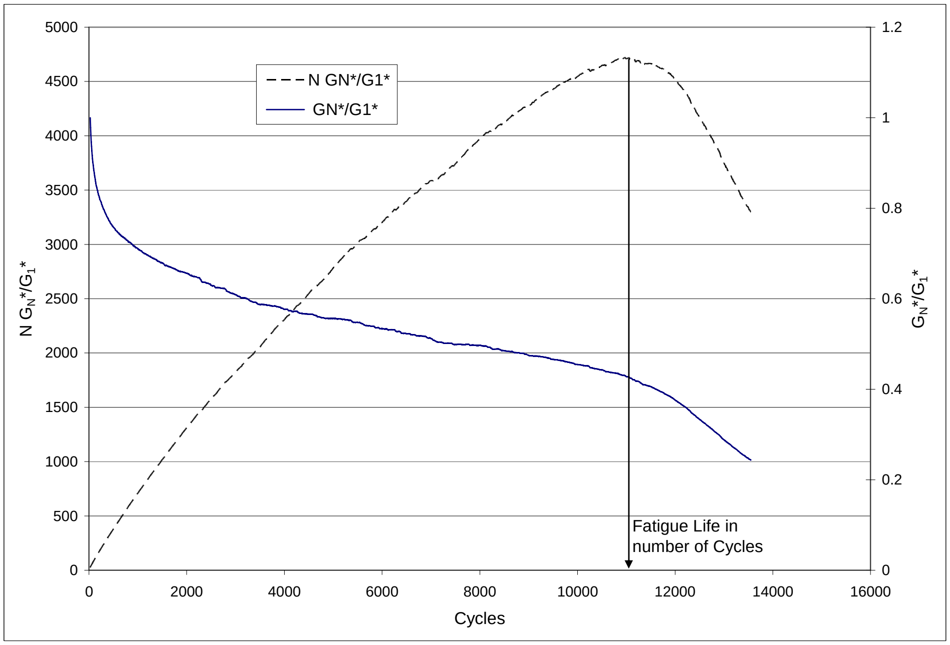

Figure 5. Typical Response Curve from DMA Test.

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.

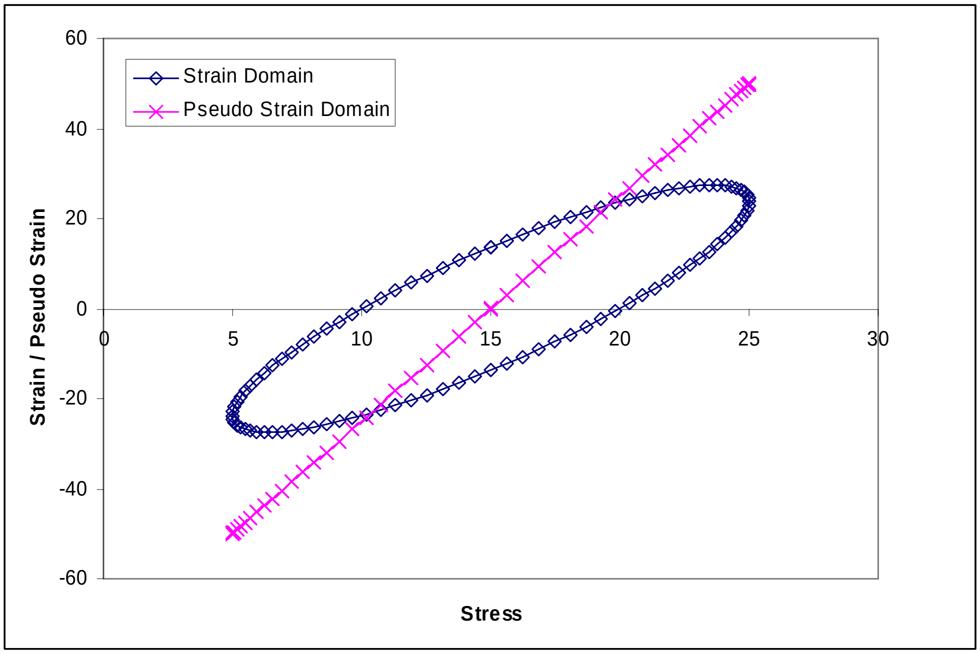

Figure 6. Comparison of stress-strain and stress-pseudo strain curve for an undamaged material.

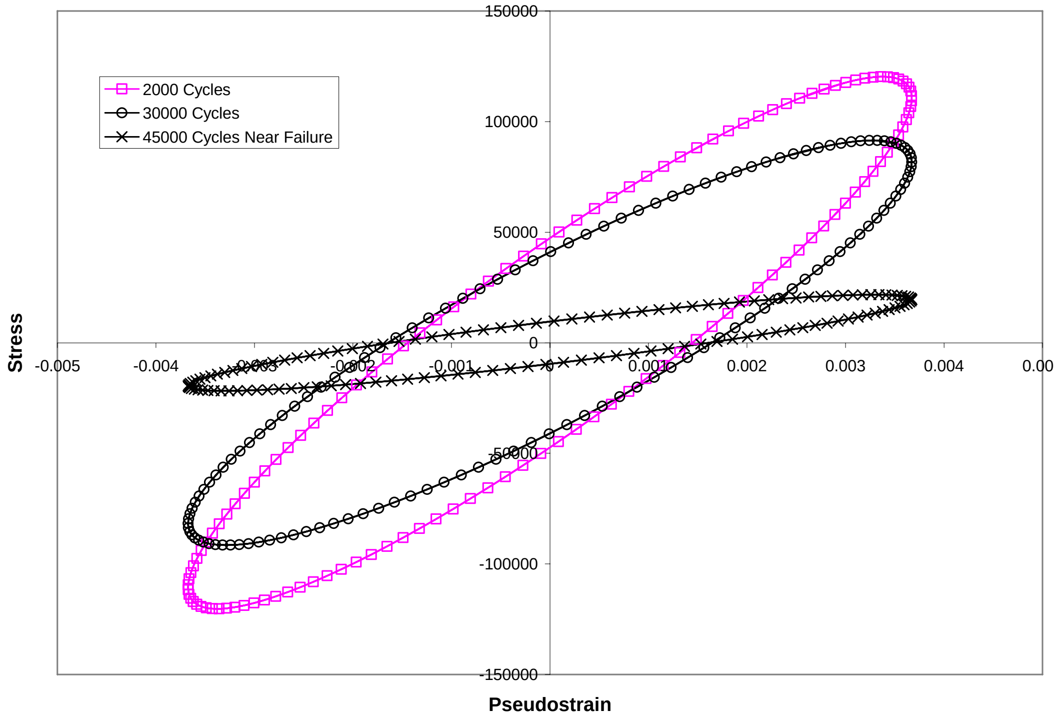

Figure 7. DPSE as a controlled strain test progresses.

Results and Discussion.

Two different types of comparisons among neat, hydrated lime, and lime prill mixes were of interest. The first was to determine whether the addition of either hydrated lime or lime prills significantly improved the damage resistance of the matrices. The second was to determine whether performance of asphalt matrices with hydrated lime was different from the performance of matrices with the lime prills. Tables 3 and 4 compare the average fatigue life and CDPSE obtained for the eleven asphalt matrices using the DMA, respectively. The average is based on a minimum of 4 replicates for each matrix type. In some cases use of hydrated lime and prills resulted in anomalous behavior of the stress-pseudo strain curves which in turn affects the computed CDPSE. However, this does not affect the measured fatigue life of the mixes. Researchers are investigating whether this behavior is due to significant differences in the rheology of the matrix or due to an artifact of the data acquisition and analysis from the DMA.

Since the standard deviation of the results obtained was high, a more rigorous statistical comparison was made among these mixes. Table 5 presents a summary of the results from the hypothesis testing using the test results from the DMA.

Table 3. Fatigue Cracking Life of Mastic Samples.

	Average Fatigue Life (x1000 cycles)					Standard Deviation of Fatigue Life (x1000 cycles)				
	Neat	Hyd. Lime	Prills Type 1	Prills Type 2	Prills Type 3	Neat	Hyd. Lime	Prills Type 1	Prills Type 2	Prills Type 3
AAD	7.8	29.2	39.9	18.9	16.4	4.9	14.2	20.9	10.1	14.5
AAB	6.3	12.4	--	--	16.7	4.9	5.3	--	--	8.7
ABD	5.7	3.1	--	--	2.2	1.0	0.4	--	--	0.4

Note: Hyd. Lime is Hydrated Lime
-- indicates that tests were not conducted for these combinations

Table 4. CDPSE in Mastic Samples.

	Average CDPSE (x10^6 N-m/m^3)					Standard Deviation of Fatigue Life (x10^6 N-m/m^3)				
	Neat	Hyd. Lime	Prills Type 1	Prills Type 2	Prills Type 3	Neat	Hyd. Lime	Prills Type 1	Prills Type 2	Prills Type 3
AAD	18.9	42.4	89.0	37.7	30.7	13.3	17.2	56.3	18.5	28.8
AAB	11.9	50.9	--	--	51.7	8.8	24.7	--	--	34.5
ABD	12.2	14.6	--	--	9.4	5.5	5.1	--	--	4.2

Note: Hyd. Lime is Hydrated Lime
-- indicates that tests were not conducted for these combinations

Table 5. Hypothesis Tests to Evaluate Influence of Prills.

Asphalt Binder	Param-eter	H_0: Neat Mix = Hydrated Lime Mix		H_0: Neat Mix = Lime Prill Mix		H_0: Hydrated Lime Mix = Lime Prill Mix	
		H_a: Neat Mix < Hydrated Lime Mix		H_a: Neat Mix < Lime Prill Mix		H_a: Hydrated Lime Mix ≠ Lime Prill Mix	
		p-value	Reject H_0 for H_a	p-value	Reject H_0 for H_a	p-value	Reject H_0 for H_a
AAD	Fatigue	0.013	Yes	0.006	Yes[1]	0.358	No[1]
				0.015	Yes[1]	0.082	No[1]
				0.023	Yes[2]	0.198	No[2]
	CDPSE	0.027	Yes	0.035	Yes[2]	0.972	No[2]
				0.103	No[3]	0.196	No[3]
				0.195	No[3]	0.628	No[3]
AAB	Fatigue	0.040	Yes	0.016	Yes[3]	0.284	No[3]
	CDPSE	0.015	Yes	0.027	Yes[3]	0.959	No[3]
ABD	Fatigue	0.499	No	0.499	No[3]	0.001	Yes[3]
	CDPSE	0.216	No	0.337	No[3]	0.048	Yes[3]

Note: [1] Type 1 Prills
[2] Type 2 Prills
[3] Type 3 Prills

From the comparison of average values and statistical analysis the following conclusions are drawn:

- The average fatigue life and CDPSE increased with the addition of hydrated lime or lime prills to the asphalt matrix in all cases with the exception of asphalt binder ABD. Results from this study are in concordance with the findings from other studies that indicate that the asphalt binder AAD is very reactive to addition of active fillers such as hydrated lime where as the binder ABD is relatively less reactive.
- Based on the statistical analysis, addition of hydrated lime resulted in significant improvement ($\alpha = 0.05$) to the fatigue cracking life and CDPSE of the asphalt matrix in all cases except with asphalt binder ABD. Addition of lime prills had a similar effect except for type 3 prills with AAD. This could be because of the poor dispersion of type 3 prills in this asphalt binder AAD.

- Based on the statistical analysis, the performance of asphalt matrix with hydrated lime was not significantly different from the performance of asphalt matrix with lime prills in all cases except with the asphalt binder ABD.

Conclusions

In this study, eleven different types of asphalt matrices were tested using the DMA to evaluate whether or not lime prills can be used in lieu of hydrated lime as an active filler in hot mix asphalt. Lime prills were added to the mix in the same proportion as hydrated lime assuming 100% breakdown of prills to fines (passing #200 sieve). Type 1 prills appear to have better breakdown and dispersion than other types of prills when used with asphalt binder AAD. Type 3 prills had relatively poor breakdown and dispersion in AAD as compared to AAB and ABD. Although in practice the breakdown and dispersion of prills was not 100%, the benefits of hydrated lime from the prills in most asphalt matrices was evident in the form of improvement in the fatigue cracking life and CDPSE.

Results from this study indicate that lime prills can be used as a substitute for hydrated lime powder, provided proper breakdown and dispersion of lime prills is achieved. It is recommended that type 1 prills be used with several other types of asphalt binders to establish the quality of breakdown and dispersion.

References

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