Warm Asphalt Study

Progress Report
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Objective

The objective of this study is to develop a method for producing hot mix asphalt at lower temperatures than are normally used in hot mix asphalt production and construction. This reduced temperature asphalt has also been called warm asphalt.

One potential method for developing warm asphalt may be to introduce a small amount of water into the asphalt binder or asphalt mix to "foam" the asphalt binder. The foaming action that occurs from mixing water and asphalt results in an increase in the volume of the asphalt binder as well as a decrease in its viscosity. This volume increase/viscosity decrease may allow the binder to more easily mix with aggregate and be compacted at temperatures much lower than normal.

Additives

Initial work indicated that the addition of a small amount of water to hot asphalt binder could "foam" the asphalt thus greatly increasing the asphalt binder volume and decreasing its viscosity for a short amount of time. Furthermore, it was found that delivering the water into the asphalt through some type of "carrier" such as a mineral material may be the optimum method for foaming the asphalt. This was discovered through trial testing that indicated that adding water directly to asphalt binder and asphalt mixes did not appear to disperse the water and produce the foaming action desired. When the mineral material or other materials containing the water were added to the asphalt binder or the asphalt mix, the desired foaming action was more apparent. It was also thought that the addition of some type of chemical modifier such as a surfactant (soap) may extend the life of the foamed asphalt thus allowing for extended time of volume increase and viscosity decrease. The additives that were chosen to test these theories are shown in Table 1.

Table 1. Warm Asphalt Additives

Additive	Percent Water by Total Mix Weight
Fine aggregate partially saturated with water	0.06%
Fine aggregate partially saturated with water (double water)	0.13%
Crushed zeolite granules	0.06%
Aluminum sulfate	0.06%
Bentonite clay	0.06%
Baking soda	0.06%
Perlite partially saturated with water	0.06%
Perlite partially saturated with water (double water)	0.13%
Aspha-min (synthetic zeolite powder)	0.06%
Fine aggregate partially saturated with a 1/3 Calgon and 2/3 water solution	0.06% solution
Fine aggregate partially saturated with a 1/3 Calgon and 2/3 water solution (double solution)	0.13% solution

Fine aggregate partially saturated with a 1/3 surfactant and 2/3 water solution (All brand detergent)	0.06% solution
Fine aggregate partially saturated with a 1/3 surfactant and 2/3 water solution (All brand detergent) (double solution)	0.13% solution

Depending of the moisture content of each additive, the amount of each added to the mix was varied to achieve a total of 0.6% water by total weight of mix. This percentage of water was based on the amount of water delivered to a mixture when using 0.3% Aspha-min which is a known additive for producing reduced temperature asphalt mixes. Certain additives were used in their "as received" states which means no moisture was added to them. These include the zeolite granules, bentonite clay, aluminum sulfate, baking soda and aspha-min. In these cases, the moisture content of the as received materials was determined and used for calculating the proper amount of material to achieve 0.06% water by total weight of mix.

As explained previously, adding water directly to the asphalt binder or mixture did not appear to produce the foaming action desired. Therefore, to add water to the mixture without an additional material such as zeolite, some samples were mixed by saturating a portion of the fine aggregate. For these samples, 5% of the fine aggregate in the mixture was left out of the batch. Prior to mixing, the desired amount of water was mixed with the 5% fine aggregate and then mixed with the heated aggregates and asphalt. The amount of water used was 0.06% and 0.13%

This process was also used for the calgon and water solutions and the surfactant and water solutions. A solution of 1/3 calgon and water or 1/3 surfactant (All detergent) and water was added to 5% dry fines which was then added to the heated aggregates and asphalt. These solutions were used in an attempt to extend the life of the foam which would result in extended decreased asphalt viscosity. The amount of water used was 0.06% and 0.13%

A final product that was tested was perlite which is a lightweight, highly absorptive aggregate. Like the fines with water, the perlite was dried and then the desired amount of water was added. The semi-saturated perlite was then mixed with the asphalt mix. Five grams of dried perlite were used and either 0.6% water by weight of mix or 0.13% water by weight of mix was used.

<u>Mixing and Compaction</u>

A coarse graded 12.5 mm Superpave mix was chosen for evaluation with the various additives. Generally coarse graded mixes "resist" compaction more so than fine graded mixes. Furthermore, at compaction temperatures cooler than normal, this resistance to compaction would be increased for coarse graded mixtures. Fine graded mixtures may be easier to compact and may show very little difference in mixtures compacted at normal temperatures versus low temperatures. For this reason, a coarse graded mixture was chosen to determine if the additives would allow for easier compaction at cooler temperatures. The job mix formula for this mixture is located in Appendix A.

To test the various additives, samples of the test mixture were mixed and compacted at standard temperatures with no additives. This was considered the control mixture. The test mixture was then mixed and compacted at lower temperatures with the additives and the volumetric properties compared to the control mixture. The mixing process was as follows:

Control Mixture

1. Preheat batched aggregates to 350° F
2. Preheat asphalt binder to 325° F
3. Mix sample until coated
4. Short term age at 300° F for two hours
5. Compact samples to 100 gyrations at 300° F

Warm Asphalt Mixtures with Additives

1. Preheat batched aggregates to 300° F
2. Preheat asphalt binder to 325° F
3. Combine aggregates and asphalt and begin mixing
4. After 2 to 3 seconds mixing, add additive
5. Continue to mix until coated
6. Short term age at 250° F for two hours
7. Compact samples to 100 gyrations at 250° F (50° F below standard compaction temperture)

Initially, all samples were mixed, aged, and compacted in the Superpave gyratory compactor. During the process of mixing and compacting the samples, it was decided that a sample of the control mixture should be mixed and compacted at the lower temperatures used for the additives to determine how the mix reacted without the additives at reduced temperatures. Surprisingly, the unmodified sample compacted at 250° F had volumetric properties similar to the samples compacted at 305°F. Furthermore, a quick experiment indicated that volumetric properties were not affected for this mixture when it was compacted in the gyratory compactor at temperatures as low as 210°F. This also appeared to be the case for a fine graded mixture that was tested as well. This indicated that gyratory compaction may not be very susceptible to temperature changes and therefore would not be an appropriate method of compaction for this study.

Based on this finding, the compactor type was changed to the Asphalt Vibratory Compactor. The time required to compact the control mixture at 300°F to approximately 7% air voids was determined and set as the standard time of compaction. The control mixture was then compacted for the standard compaction time at various low temperatures to determine at what temperature a substantial change in volumetric properties was observed. This temperature was determined to be 225°F. Once the new compactor type and temperatures were determined, the mixing process was changed to the following:

Control Mixture

1. Preheat batched aggregates to 350° F
2. Preheat asphalt binder to 325° F
3. Mix sample until coated
4. Short term age at 300° F for two hours
5. Compact samples for 26 seconds at 300° F

Warm Asphalt Mixtures with Additives

1. Preheat batched aggregates to 280° F
2. Preheat asphalt binder to 325° F
3. Combine aggregates and asphalt and begin mixing
4. After 2 to 3 seconds mixing, add additive
5. Continue to mix until coated
6. Short term age at 225° F for two hours
7. Compact samples for 26 seconds at 225° F (75° F below standard compaction temperature)

In general, the mixing and compaction of the warm mixes with additives was similar to the control mixture at standard temperatures. No problems with coating were apparent at the lower temperatures nor were problems with compaction apparent at the lower temperatures. Some note worthy observations are as follows:

- The bentonite clay did not coat well initially, although it did eventually coat
- The sample with baking soda appeared to mix and coat the easiest at the low temperatures
- The samples of water with Calgon and water with surfactant released a noticeable amount of steam

Once the samples were compacted and cooled to room temperature, the volumetric properties of each was determined and compared.

Results

The air void content for the control mixture and warm mixtures are shown in Table 2. Figure 1 shows a graph of the average air void content for each mixture as well as plus and minus one standard deviation for each mixture.

An analysis of variance (ANOVA) was performed on the sample data to determine if a significant difference was present between two or more of the sample groups. As shown in Table 3, at a significance level of $\alpha = 0.05$ there is a significant difference between at least two or more of the sample groups.

To further determine which sample groups were significantly different, specifically with respect to the control samples, a t-test was performed to compare means between the control mixture compacted at 300° F and each group containing an additive and between the control mixture compacted at 225° F and each group containing an additive. The results of the t-test can be seen in Table 4.

Table 2. Air Void Content of Beam Samples Containing Various Additives

Additive	% Water	Compaction Temperature	Average Air Void Content (%)	Standard Deviation
Control 300° F	0.0	300° F	8.04	0.28
Control 225° F	0.0	225° F	10.03	0.26
Crushed Zeolite Granules	0.6	225° F	9.34	0.17
Asphamin	0.6	225° F	9.04	0.28
Crushed Bentonite	0.6	225° F	9.16	0.41
Aluminum Sulfate	0.6	225° F	8.99	0.12
Water in Fines	0.6	225° F	9.21	0.08
Water in Fines – Double	0.13	225° F	9.23	0.13
Calgon Solution	0.6	225° F	9.21	0.47
Calgon Solution – Double	0.13	225° F	8.81	0.51
Surfactant Solution	0.6	225° F	9.12	0.06
Surfactant Solution - Double	0.13	225° F	9.20	0.19
Baking Soda	0.6	225° F	8.85	0.45
Water in Perlite	0.6	225° F	8.79	0.21
Water in Perlite - Double	0.13	225° F	8.87	0.65

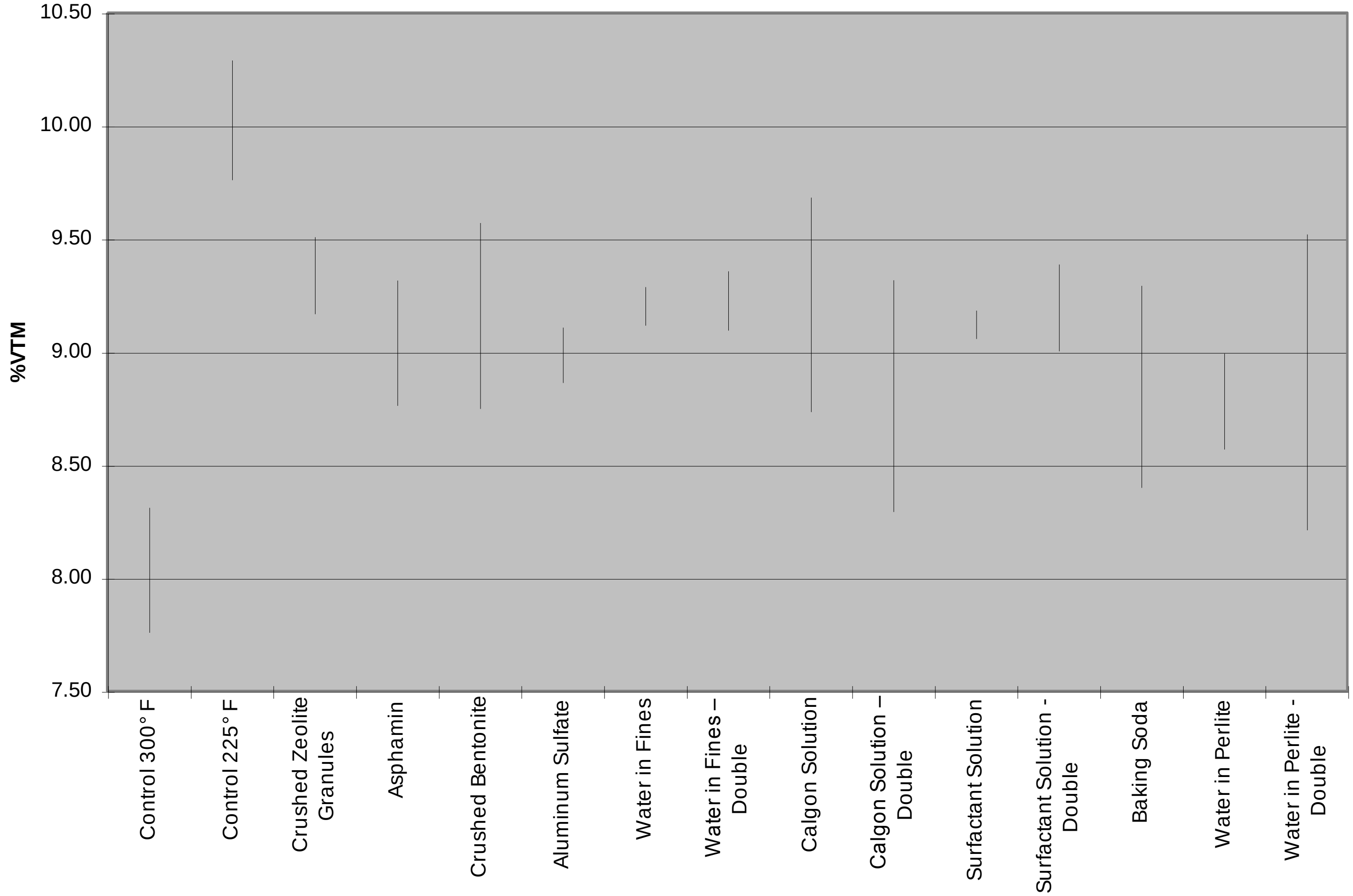

Figure1. Air Void Content Plus and Minus One Standard Deviation of Beam Samples Containing Various Additives

Table 3. ANOVA For All Sample Groups

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.17592	14	0.512566	4.637767	0.000209	2.037421
Within Groups	3.315598	30	0.11052			
Total	10.49152	44				

Table 4. t-test for Between Control Mixes and Each Sample Group
(N = no significant difference between these groups,
S = significant difference between these groups exists)

t statistic = 2.13

	Control 300° F	Control 225° F
Control 300° F		9.01 S
Control 225° F	9.01 S	
Crushed Zeolite Granules	6.96 S	3.79 S
aspha-min	4.45 S	4.46 S
Crushed Bentonite	3.94 S	3.07 S
Aluminum Sulfate	5.45 S	6.19 S
Water in Fines	7.00 S	5.13 S
Water in Fines – Double	6.75 S	4.69 S
Calgon Solution	3.71 S	2.60 S
Calgon Solution – Double	2.29 S	3.66 S
Surfactant Solution	6.64 S	5.77 S
Surfactant Solution - Double	5.97 S	4.40 S
Baking Soda	2.68 S	3.94 S
Water in Perlite	3.72 S	6.36 S
Water in Perlite - Double	2.03 N	2.84 S

The results from Table 4 indicate that the air voids of each of the mixtures containing an additive are significantly different from the control mixture compacted at 225° F. This is important since this indicates that the addition of each of the additives to this mixture results in a significantly lower compacted air void level at 225° F than the mix with no additive. This further indicates that the additives are having some effect on the compactability of the asphalt mixture. It can also be seen in Table 4 that the air voids of the control mixture compacted at 300° F are significantly different from the voids of the control mixture compacted at 225° F. This indicates that the reduced compaction temperature does in fact have an effect on the compacted air voids of the control mixture.

The results from Table 4 also indicate that the air voids of the control mixture compacted at 300° F are significantly lower than most of the mixes with additives. Only one mixture, the perlite with double water, was not significantly different from the control mixture at 300° F. This indicates that even though the additives are having some effect on the compactability of the mixtures at lower temperatures, they do not reduce the viscosity of the asphalt binder enough to result in compacted air void levels similar to the control mixture at 300° F.

Table 5 shows the results of a t-test for the mix containing aspha-min compared to each of the other additives. This comparison was performed since aspha-min is a known and accepted product for producing low-temperature asphalt. The results from Table 5 indicate that there is no significant difference between the compacted air voids of the mix containing aspha-min and the compacted air voids of the mixes containing the other additives. This indicates that there is no significant difference in the effect of aspha-min on asphalt mixes and the other additives for this temperature range. It should be noted that the temperature range used in this study is lower than that recommended for aspha-min which is typically 50° F below standard compaction temperatures.

Table 5. t-test for Between aspha-min Mixes and Each Sample Group
(N = no significant difference between these groups,
S = significant difference between these groups exists)

t statistic = 2.78 (two tailed test)

	aspha-min
Crushed Zeolite Granules	1.59 N
aspha-min	
Crushed Bentonite	0.42 N
Aluminum Sulfate	0.31 N
Water in Fines	0.97 N
Water in Fines – Double	1.05 N
Calgon Solution	0.54 N
Calgon Solution – Double	0.70 N
Surfactant Solution	0.49 N
Surfactant Solution - Double	0.80 N
Baking Soda	0.64 N
Water in Perlite	1.28 N
Water in Perlite - Double	0.42 N

Conclusions

Conclusions from this portion of the study are as follows:

- The addition of all the additives tested resulted in an increased ease of compaction at reduced compaction temperatures (up to 75° F lower than normal) compared to the mix with no additives.

- Only one of the additives tested, perlite containing 0.13% water by mix weight, resulted in a compacted air void level similar to that of the control mixture at 300° F.
- In general, the additives tested resulted in lower compacted air voids than the control mix compacted at 225°F. However, the additives tested resulted in higher compacted air voids than the control mix at compacted at 300° F. This indicates that these additives can be used to produce and compact asphalt mixes at lower temperatures, however these mixes may still be more difficult to compact relative to standard compaction temperatures. This may indicate that a compaction temperature slightly higher than 225° may be required for these additives.
- The additives tested demonstrated a similar effect on the asphalt mixes when compared to aspha-min, a known additive for producing low temperature asphalt.
- The reduction of mixing and compaction temperatures that may result from the use of these additives could result in lower heating costs as well as fewer emissions from asphalt plants as compared to standard HMA.

Further Testing

The next step in this study will be to compact control samples and samples containing the various additives to a consistent void level (7% +/- 1%) and perform performance testing.

APPENDIX A

Job Mix Formula for the Mix Used in This Study

Superpave 12.5 mm Job Mix Formula

	Blend 1
#7	34.0
#89	23.0
W10	10.0
M10	32.0
Lime	1.0
Sieve Size	Gradation
19.00	100.0
12.50	98.9
9.50	83.7
4.75	49.0
2.36	34.6
1.18	24.8
0.60	15.6
0.30	8.7
0.150	5.1
0.075	4.0

% Asphalt Content	4.7
%VTM	4.0