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EFFECTS OF SHORT TERM OVEN AGING ON VOLUMETRICS AND SELECTION OF N-DESIGN

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A report of the findings of:
SHRP Asphalt Testing for
Performance Specifications

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16. Abstract

This report presents findings on the effect of conditioning time on the volumetric properties of Superpave Gyratory Compactor (SGC) prepared asphalt mixtures. Field mixtures were sampled from the producing plants and then recreated in the laboratory following 3 different short-term conditioning procedures to measure the effect on the N-design value of the mixture. The projects selected represent three different N-design levels, have different nominal maximum aggregate size, aggregate sources, and asphalt binder types.

Bulk Specific Gravity (Gmb) samples were aged at compaction temperature for 1-hr, 2-hr, and 4-hr. Maximum Specific Gravity (Gmm) samples were also aged at compaction temperature for 0-hr, 2-hr, and 4-hr. The short-term aging times are based off of Illinois Department of Transportation aging procedures, current National Center for Asphalt Technology recommendations, and the original Superpave conditioning specifications.

It was observed in this study that increased conditioning time has a greater impact on the volumetric properties of polymer-modified binder mixes than on neat binder mixes. Also, noticed is that the presence of polymers in the binder appears to have greater effect than the higher temperatures used for conditioning polymer-modified HMA.

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INTRODUCTION

As a part of the SUPERPAVE volumetric mix design procedure sample specimens, are compacted in the SUPERPAVE gyratory compactor (SGC) to establish the number of gyrations required to achieve 4 percent air voids in the mixture. This number of gyrations is known as the N-design. By varying the level of the N-design it is believed that mixtures can be developed to perform well under the various traffic levels that exist on the nation's asphalt paved roads. The current accepted standard is TP MP2-99, Standard Specification for SUPERPAVE Volumetric Mix Design.

The Illinois Department of Transportation, through the Superpave Implementation Committee, examined historical data on Marshall mix performance and design characteristics and correlated these with gyratory compaction characteristics. This database examination established an N-design table for use on Illinois SUPERPAVE projects in coordination with their gyratory mix design procedures. This table is similar to that proposed by a National Center for Asphalt Technology study and recommended by the mixtures expert task group (ETG).(1) However the Illinois N-design table is consistently lower in the number of gyrations recommended for a specific traffic level. This modified table was used by the Illinois DOT for the 1999 construction season and will be used in foreseeable construction seasons. The SUPERPAVE and Illinois Modified N-design values are summarized in Table 1.

The Illinois DOT modifications were developed to address what were felt to be inconsistencies between the SUPERPAVE procedures and mixture requirements historically needed for Illinois conditions. Under current SUPERPAVE recommendations, samples used for volumetric mix design should be short-term aged for two hours in a forced draft oven.(1) Field data indicated for typical Illinois mixtures this aging procedure results in a mixture with an excess of asphalt binder, typically between 0.2 and 0.4 percent by weight, which was commonly removed once production began. Thus, the mixture produced was not the same as the mixture that was evaluated for design.

Table 1 – N-design Summary Table, Comparing NCAT and IDOT Values.

Design ESALs (millions) Based on 20-year design	NCAT N_{des} Values	Illinois Modified N_{des} Values	Typical Roadway Application
< 0.3	50	30	Roadways with very light traffic volume such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Special purpose roadways serving recreational sites or areas may also be applicable.
0.3 to 3	75	50	Includes many collector roads or access streets. Medium-trafficked city streets and the majority of county roadways.
3 to 10	100	70	Includes many two-lane, multi-lane, divided, and partially or completely controlled access roadways. Among these are medium-to-highly trafficked streets, many state routes, U.S. highways, and some rural interstates.
10 to 30		90	May include the previous class of roadways that have a high amount of truck traffic.
> 30	125	105	Includes U.S. Interstates, both urban and rural in nature. Special applications such as truck-weighing stations or truck-climbing lanes on two-lane roadways may also be applicable to this level.

Based on past studies by Bell et al.[2] and Jones and Youtcheff,[3] the aging experienced by the asphalt mix during production and lay-down can be accurately reproduced in the laboratory by oven aging samples for 4 hours at 135 °C (275 °F). Further study by E.R. Brown et al.[1] has indicated that for low absorptive aggregate, those having less than 2.0% water absorption values, 2 hours of aging is sufficient for conditioning volumetric samples. It has also been shown that aging of asphalt concrete is affected by the aggregate-binder interaction and that aging cannot be simply quantified by aging the binder alone. Sosnovske, AbWahab, and Bell[4] found that aging of certain asphalts is eased by some aggregates but not by others, and that adhesion between the asphalt and aggregate appears to be a factor.

To obtain results closer to what is being constructed in Illinois the Illinois DOT has implemented two different aging procedures; whose use is dependent on the absorption properties of the aggregate. Mixtures containing aggregates with absorption properties that are less than 2.5 percent are considered low-absorptive by the Illinois DOT and they shall be conditioned for 1 hour for Bulk Specific Gravity specimens (G_{mb}), while the Maximum Specific Gravity specimens (G_{mm}) are not subjected to any conditioning requirements. This method provides good correlation between the laboratory designed mix and plant Quality Control/ Quality Assurance (QC/QA) data. For mixtures that contain high-absorptive aggregate or slag, the conditioning requirement is for all volumetric samples to be conditioned for 2 hours. Another modification that has been implemented by the Illinois DOT is to condition the samples at the compaction temperature instead of 135 °C (275 °F).

The use of the different conditioning methods for the volumetric samples results in a mixture that reaches 4 percent air voids at a lower gyration level. The goal of this study is to verify that the changes made by Illinois DOT to reduce the excess binder are valid for the conditions present with the materials used in Illinois, while still providing the same mixture design as might be expected from the SUPERPAVE procedures. This report has been undertaken for the Illinois Department of Transportation by the Advanced Transportation Research and Engineering Laboratory (ATREL).

EXPERIMENTAL PROCEDURE

Projects from around the state of Illinois were selected to verify that the modifications to the N-design table were valid for the range of materials used in construction of their asphalt-paved roads. Only mixtures designed using the Illinois modified SUPERPAVE procedure were sampled and tested in this study. The projects selected represent three different N-design levels, have different nominal maximum aggregate size, aggregate sources, and asphalt binder type. All materials obtained were from Illinois DOT certified sources and collected following IDOT sampling standards.

Six projects were identified as meeting the study criteria and are referred to as mixtures N1 through N6. Once replicated in the lab, each mix was subjected to the following three conditioning practices: Illinois modified Low-absorptive aggregate procedure (ILA), Illinois modified High-absorptive aggregate procedure (IHA), and AASHTO MP 2-99 (SHRP). Mixes N1, N2, and N3 are polymer-modified mixes while mixes N4, N5, and N6 all contain neat binders. In addition to these six mixes, mix N5 was recreated using a polymer modified binder and conditioned at neat binder temperatures to determine what impact the polymers had on aging. The mix blending percentages and aggregate properties can be found in the appendix.

Mixture Characteristics

Polymer-Modified Binder Mixtures

Mix N1 has an N_{des} value of 90 gyrations, a nominal maximum aggregate size of 19-mm (3/4-in.), and was mixed with a SHRP PG 70-22 polymer-modified asphalt binder. The mixture contained slag sand as one of its fine aggregate components and was designed following the IHA procedure. Mixtures N2 and N3 both have an N_{des} level of 105 gyrations, were mixed with a PG 70-22 polymer-modified asphalt binder, and were designed following the ILA method, as all the aggregates used are considered low-absorptive (less than 2.5 percent). Mixture N2 has a nominal maximum aggregate size of 9.5-mm (3/8-in.) and mix N3 has a nominal maximum aggregate size of 19-mm (3/4-in.).

Neat Binder Mixtures

All of the non-polymer modified mixes were produced with a PG 64-22 asphalt binder and were designed following the ILA conditioning procedure. Mix N4 is a typical Illinois binder course mixture for a two-lane rural highway; it has an N_{des} value of 50, and has a nominal maximum aggregate size of 19.5-mm (3/4-in.). The N_{des} value for mix N5 is 90 gyrations, has a nominal maximum aggregate size of 19.5-mm (3/4-in.), and is typical of a binder course that the Illinois DOT has placed on rural interstate routes. Mix N6 may be considered a typical surface coursed placed on medium trafficked city streets and County roadways. It has an N_{des} level of 50 and a nominal maximum aggregate size of 12.5-mm (1/2-in.).

Additional Mixture

Based on initial results it was noticed that the differences in the conditioning procedures appeared to effect the volumetric properties of the polymer-modified mixes greater than it effected the volumetric properties of the neat binder mixes. An additional mixture was evaluated to determine whether the difference was the result of having polymers in the binder or from having a higher prescribed conditioning temperature. This additional mixture was produced using the same aggregate structure as mix N5, a non-modified mix, but was combined using a polymer modified PG 70-22 binder in order to measure the affect of temperature on aging. To gauge this effect mix N5M was created and conditioned under the same guidelines that are required for a mixture that contains a neat binder.

Sampling

The materials tested were sampled directly from the producing plant several days after initial construction of the project had begun. Six sample bags of hot mix asphalt (HMA) were obtained directly from the box of a truck immediately after the truck was loaded so mixture characterization could be performed in the lab. Five gallons of AC binder and several bags of aggregate per stockpile were also sampled in order to reproduce the mix at ATREL.

Specimen Preparation

The aggregate structure selected by the Illinois DOT for these mixtures was replicated in the laboratory and the mix design at optimum asphalt content was verified using IDOT procedures. This allowed for the establishment of the number of gyrations needed to achieve 4 percent air voids in the mix. The mixture was then reproduced following AASHTO TP 4-99 recommendations for short-term aging.

Steps were taken to ensure that the laboratory reproduced specimens met the same gradations outlined in the mixture design. Once sampled, all aggregates were sieved down to their component sizes and later recombined following the mixture gradation. The samples were then tested using IDOT Modified AASHTO T 11-91 “Materials Finer than 75-µm Sieve in Mineral Aggregates by Washing,” IDOT Modified AASHTO T 27-93 “Sieve Analysis of Fine and Coarse Aggregates,” and the IDOT Procedure for Dust Correction Factor Determination. This last step was performed to account for any additional minus 75-µm (No. 200) materials that may be present as a result of batching with unwashed aggregates.

Once gradations were confirmed, twelve samples were batched and prepared for mixing. Prior to mixing, all batched aggregates were placed in the oven for a minimum of twelve hours to ensure that all moisture had been from the aggregate. Mixing was then executed following the

Illinois modification requiring that all unmodified asphalts be mixed at a temperature of 146 ± 3 °C (295 ± 5 °F), and that all polymer-modified asphalts be mixed at 163 ± 3 °C (325 ± 5 °F). Three of the samples were later split in half for G_{mm} determination, which provided two samples per aging procedure per mix. The remaining nine samples were conditioned for G_{mb} specimens; three compacted specimens per aging procedure. Immediately following mixing, each sample was then short-term aged in a forced-draft oven for the required time by each of the conditioning procedures. During the short-term aging, all samples were stirred every hour to ensure uniform aging throughout the mix.

Regardless of conditioning procedure, all specimens were compacted to the N_{des} level outlined by the Illinois DOT procedure. As stipulated by Illinois Modified PP 2-99, all non-modified binders are conditioned and compacted at 146 ± 3 °C (295 ± 5 °F) and all polymer-modified binders are conditioned and compacted at 152 ± 3 °C (305 ± 5 °F). Compaction was performed using the Servopac IPC pneumatic controlled gyratory compactor due to its ability to provide information on the shear stress of the sample during compaction. Studies conducted at ATREL on the IDOT Round Robin testing programs have shown the volumetric properties obtained from the Servopac SGC are identical to the results obtained from both the Troxler SGC and the Pine SGC.

Volumetric testing was performed to determine the air voids present in the compacted samples, and the back-calculation to N-design was performed. Volumetric testing was conducted following Illinois Modified T 209-94 Maximum Specific Gravity of Bituminous Paving Mixtures and Illinois Modified T 166-93 Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface Dry Specimens.

N_{des} Back-calculation

By utilizing the back-calculation procedure outlined by Vavrik,[4] a direct comparison will be made indicating the impact of IDOT aging on the mix design values relative to AASHTO recommendations. The procedure used in the back-calculation of air voids generally uses only the height data obtained to a specified height, based on engineering judgment or the locking point of the compacted sample. The data is then converted to percent maximum specific gravity (%Gmm) and plotted versus number of gyrations using a logarithmic relationship. The plot is then analyzed using a statistical regression curve. Finally, a linear regression is fit to the data, excepting the first gyration, using a method of least squares and a number of gyrations are determined.

RESULTS

The effects of the different conditioning procedures on the volumetric properties, and ultimately the N_{des} value, will now be discussed. A Fisher's LSD analysis has been performed on the data to determine the statistical significance of the different aging procedures based on the air voids and the back-calculated N_{des} value. The reported values include individual sample measurements as well as mean values, standard deviations, and coefficients of variation for each of the conditioning procedures.

Volumetrics

Polymer-Modified Binder Mixtures

Mixes N1, N2, N3, and N5M all contain polymer-modified binders and show greater influence from short-term aging. Figures 1 through 3 show the trends in Gmm, Gmb, and air voids as a result of the different conditioning times. The inclusion of N5M in the results reveals that it is the presence of the polymers in the binder, and not the increased conditioning temperature, that causes these mixes to "age" more significantly.

For mix N1 the average percent air voids, after compacting to 90 gyrations, are 3.90%, 4.66%, and 5.38% for the ILA, IHA, and SHRP procedures, respectively. The coefficients of variation (COVs) for this mix by procedure are: 2.34% for ILA, 3.17% for IHA, and 1.46% for SHRP. Mix N2 was compacted to 105 gyrations, which created mean air voids of 4.44%, 5.85%, and 6.57% for ILA, IHA, and SHRP procedures, respectively. The corresponding COVs are 0.87%, 0.85%, and 1.33%. Mix N3 was also compacted to 105 gyrations and developed mean air voids of 4.51%, 5.77%, and 6.42% and COVs of 2.94%, 5.27%, and 4.97% for ILA, IHA, and SHRP, respectively. Mixture N5M was a 90-gyration mix that developed mean air voids of

3.33%, 4.13%, and 4.86% with COVs of 3.40%, 5.03%, and 4.50% for ILA, IHA, and SHRP, respectively.

From the air void results it can be seen that the recreation of field mixes in the lab may not result in exactly 4% air voids. The recreated mixes, each following the appropriate IDOT design, typically had air voids within plus or minus one-half a percent of 96% of Gmm. Based on the COVs it can be seen that the individual samples did not deviate far from the mean values which, demonstrates consistency in testing. The results of all the volumetric testing can be seen in Tables 2 through 8.

Neat Binder Mixes

The mixes created using neat binders also had a trend of increasing air voids as conditioning time increased, but it was not as pronounced. Mix N4 was compacted to 50 gyrations and has mean air voids of 4.49%, 5.09%, and 5.24% with corresponding COVs of 2.71%, 0.09%, and 2.28% for ILA, IHA, and SHRP, respectively. After 90 gyrations, mix N5 developed mean air voids of 3.70%, 3.93%, and 3.98% and has COVs of 3.41%, 3.12%, and 4.70% for ILA, IHA, and SHRP, respectively. Mix N6 is another 50-gyration design and developed mean air voids of 3.50%, 4.05%, and 4.33% and COVs of 3.43%, 3.05%, and 1.85%. The neat binder mixes, like the polymer-modified mixes, did not reproduce exactly to 4% air voids, but the variation remains within plus or minus one-half a percent.

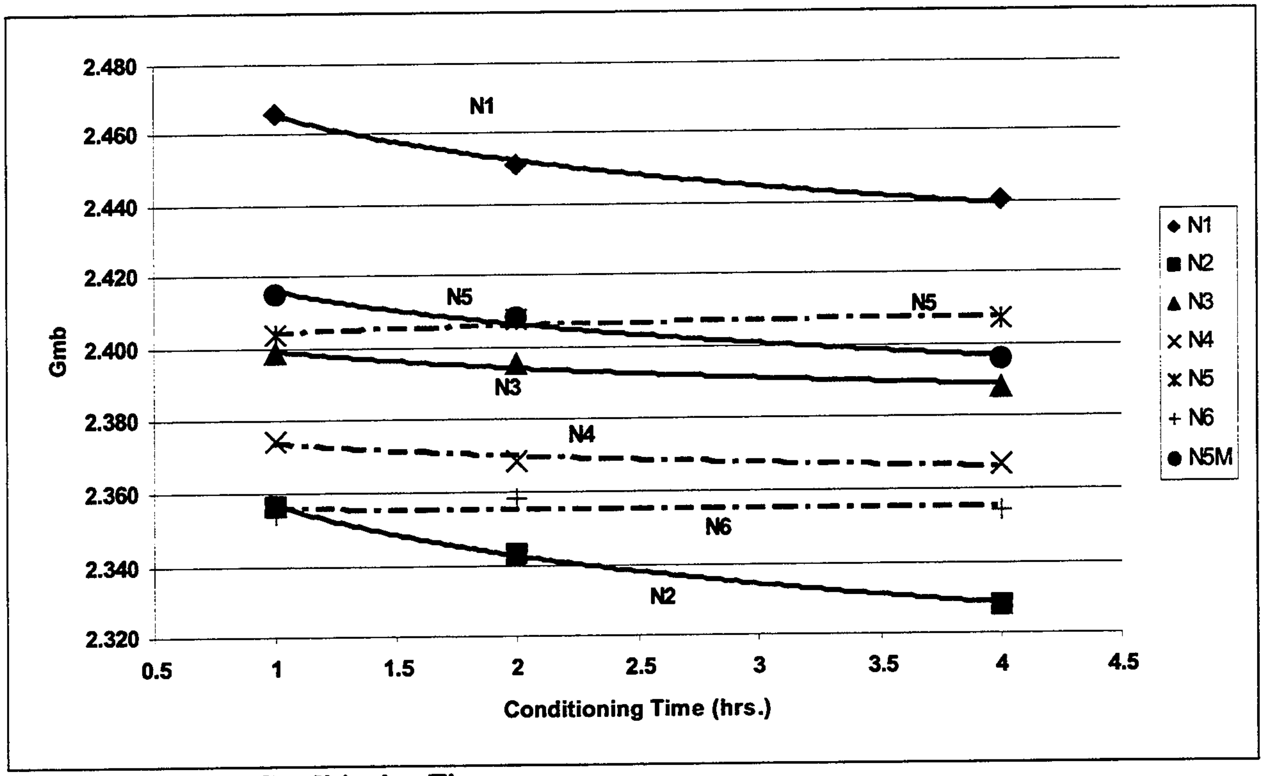

Figure 5 – Gmb vs. Conditioning Time

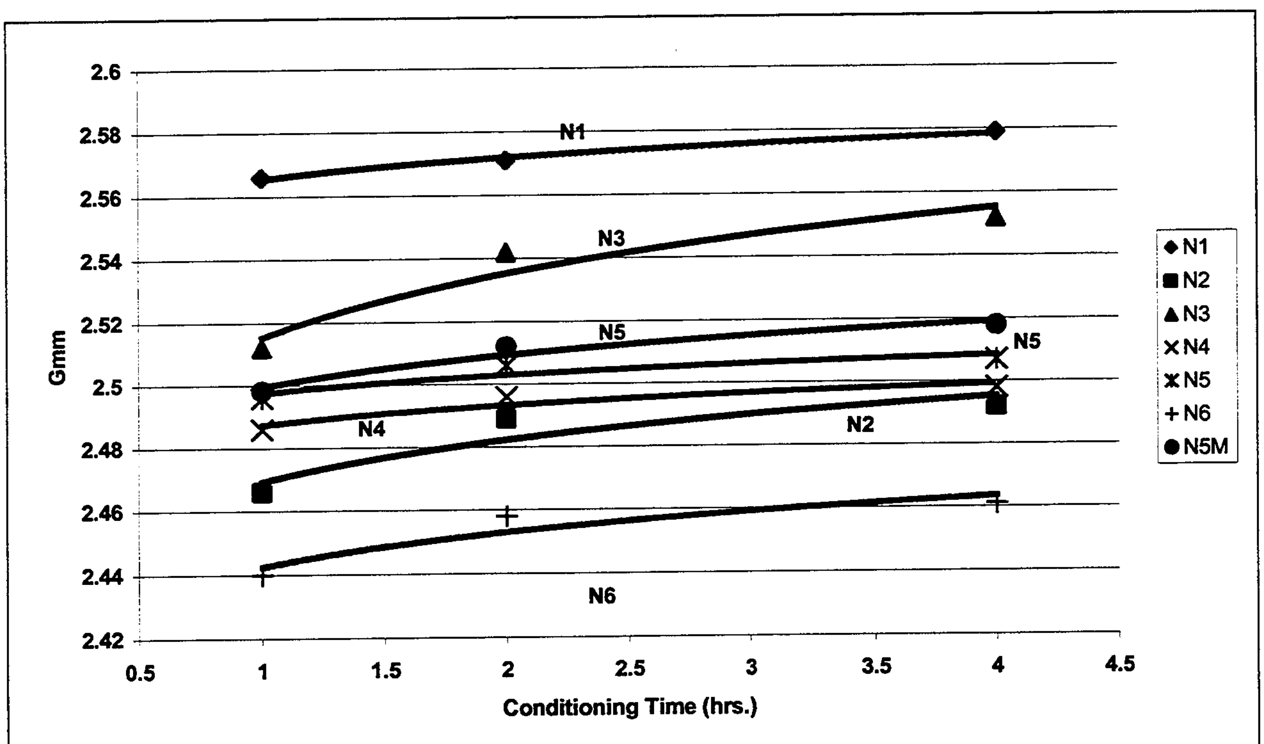

Figure 6 – Gmm vs. Conditioning Time

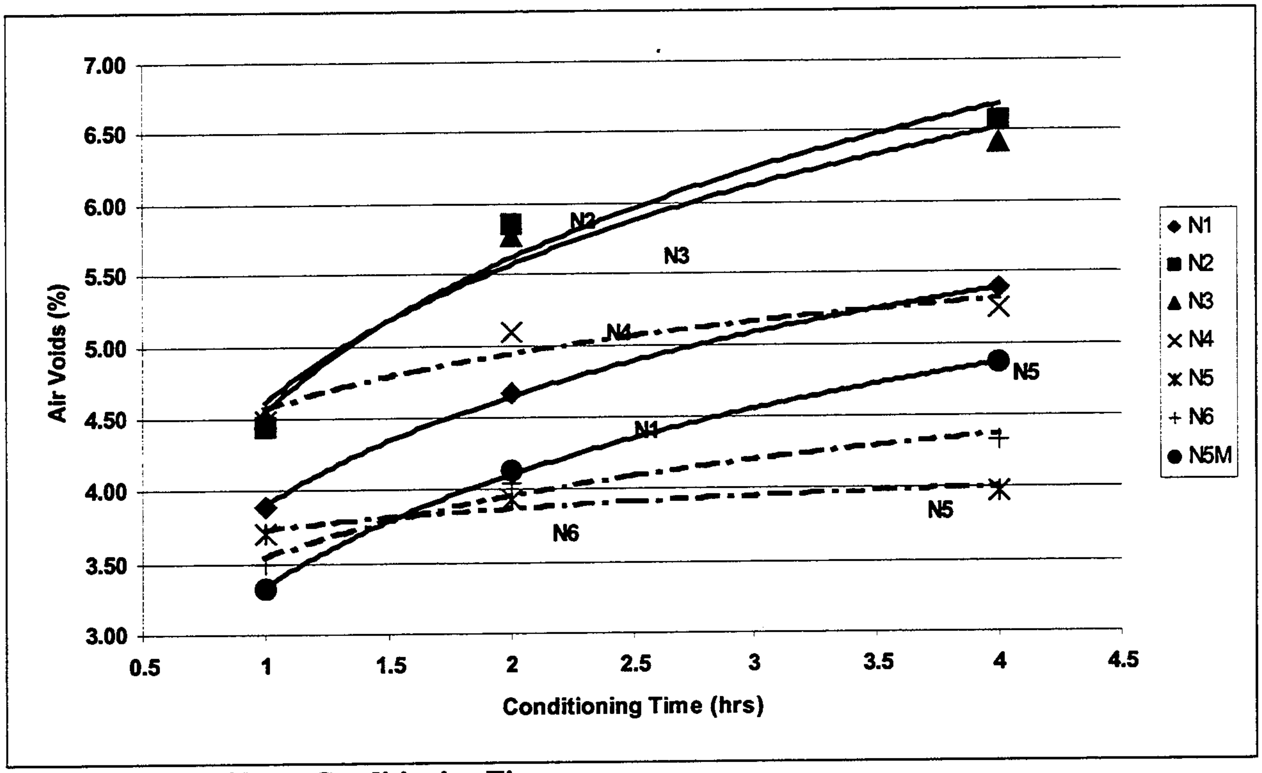

Figure 7 – Air Voids vs. Conditioning Time

Table 2 – Mix N1 Volumetric Data

Binder Percent (mix)	Pb	4.800
Binder Percent (agg)	Pb	5.042
Binder Spec. Gravity	Gb	1.038
Stone Bulk Spec. Gravity	Gsb	2.709
Percent Passing 0.075 mm	<0.075	4.634
Dust Proportion		1.179
Apparent Binder Content	Pba	0.869
Effective Binder Content	Pbe	3.931

Ndes	90

IDOT Low-Absorptive Conditioning Procedure

	Sample	N1-1	N1-2	N1-3	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.772				
Maximum Specific Gravity	Gmm		2.566				
Bulk Specific Gravity	Gmb	2.464	2.468	---	2.466	0.00	0.09%
Air Voids	Va	3.96	3.83	---	3.90	0.09	2.34%
Voids in Mineral Aggregate	VMA	13.39	13.28	---	13.33	0.08	0.96%
Voids Filled with Asphalt	VFA	70.43	71.14	---	70.79	0.50	0.71%

IDOT High-Absorptive Conditioning Procedure

	Sample	N1-4	N1-5	N1-6	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.778				
Maximum Specific Gravity	Gmm		2.571				
Bulk Specific Gravity	Gmb	2.455	2.447	2.451	2.451	0.00	0.16%
Air Voids	Va	4.51	4.81	4.67	4.66	0.15	3.17%
Voids in Mineral Aggregate	VMA	13.72	13.99	13.87	13.86	0.13	0.96%
Voids Filled with Asphalt	VFA	67.11	65.63	66.30	66.35	0.74	1.12%

SUPERPAVE Original Conditioning Procedure

	Sample	N1-7	N1-8	N1-9	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.788				
Maximum Specific Gravity	Gmm		2.579				
Bulk Specific Gravity	Gmb	2.442	2.438	2.440	2.451	0.00	0.08%
Air Voids	Va	5.30	5.45	5.40	5.38	0.08	1.46%
Voids in Mineral Aggregate	VMA	14.17	14.31	14.26	14.24	0.07	0.50%
Voids Filled with Asphalt	VFA	62.60	61.88	62.14	62.21	0.36	0.58%

Table 3 – Mix N2 Volumetric Data

Binder Percent (mix)	Pb	5.300			
Binder Percent (agg)	Pb	5.597			
Binder Spec. Gravity	Gb	1.030			
Stone Bulk Spec. Gravity	Gsb	2.606			
Percent Passing 0.075 mm	<0.075	4.611			
Dust Proportion		1.077			
Apparent Binder Content	Pba	1.017			
Effective Binder Content	Pbe	4.283		Ndes	105

IDOT Low-Absorptive Conditioning Procedure

	Sample	N2-1	N2-2	N2-3			
Stone Effective Spec. Gravity	Gse		2.675				
Maximum Specific Gravity	Gmm		2.466		Average	Std. Dev.	COV
Bulk Specific Gravity	Gmb	2.357	2.357	2.356	2.357	0.00	0.04%
Air Voids	Va	4.41	4.42	4.48	4.44	0.04	0.87%
Voids in Mineral Aggregate	VMA	14.33	14.35	14.40	14.36	0.03	0.24%
Voids Filled with Asphalt	VFA	69.26	69.18	68.89	69.11	0.19	0.28%

IDOT High-Absorptive Conditioning Procedure

	Sample	N2-4	N2-5	N2-6			
Stone Effective Spec. Gravity	Gse		2.703				
Maximum Specific Gravity	Gmm		2.489		Average	Std. Dev.	COV
Bulk Specific Gravity	Gmb	2.345	2.342	2.344	2.343	0.00	0.05%
Air Voids	Va	5.80	5.90	5.84	5.85	0.05	0.85%
Voids in Mineral Aggregate	VMA	14.80	14.89	14.83	14.84	0.05	0.30%
Voids Filled with Asphalt	VFA	60.77	60.34	60.61	60.57	0.22	0.36%

SUPERPAVE Original Conditioning Procedure

	Sample	N2-7	N2-8	N2-9			
Stone Effective Spec. Gravity	Gse		2.707				
Maximum Specific Gravity	Gmm		2.492		Average	Std. Dev.	COV
Bulk Specific Gravity	Gmb	2.327	2.331	2.326	2.328	0.00	0.09%
Air Voids	Va	6.60	6.48	6.64	6.57	0.09	1.33%
Voids in Mineral Aggregate	VMA	15.42	15.30	15.45	15.39	0.08	0.51%
Voids Filled with Asphalt	VFA	57.17	57.68	57.02	57.29	0.35	0.61%

Table 4 – Mix N3 Volumetric Data

Binder Percent (mix)	Pb	4.400
Binder Percent (agg)	Pb	4.603
Binder Spec. Gravity	Gb	1.038
Stone Bulk Spec. Gravity	Gsb	2.636
Percent Passing 0.075 mm	<0.075	4.518
Dust Proportion		1.239
Apparent Binder Content	Pba	0.753
Effective Binder Content	Pbe	3.647

Ndes	105

IDOT Low-Absorptive Conditioning Procedure

	Sample	N3-1	N3-2	N3-3	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.688				
Maximum Specific Gravity	Gmm		2.512				
Bulk Specific Gravity	Gmb	2.393	2.404	2.399	2.399	0.01	0.24%
Air Voids	Va	4.75	4.30	4.49	4.52	0.22	4.97%
Voids in Mineral Aggregate	VMA	13.24	12.83	13.00	13.02	0.20	1.57%
Voids Filled with Asphalt	VFA	64.10	66.44	65.45	65.33	1.18	1.80%

IDOT High-Absorptive Conditioning Procedure

	Sample	N3-4	N3-5	N3-6	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.724				
Maximum Specific Gravity	Gmm		2.542				
Bulk Specific Gravity	Gmb	2.404	2.390	2.391	2.395	0.01	0.32%
Air Voids	Va	5.42	5.97	5.93	5.77	0.30	5.27%
Voids in Mineral Aggregate	VMA	12.82	13.32	13.28	13.14	0.28	2.13%
Voids Filled with Asphalt	VFA	57.70	55.20	55.38	56.09	1.40	2.49%

SUPERPAVE Original Conditioning Procedure

	Sample	N3-7	N3-8	N3-9	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.736				
Maximum Specific Gravity	Gmm		2.552				
Bulk Specific Gravity	Gmb	2.393	2.388	2.384	2.388	0.00	0.20%
Air Voids	Va	6.23	6.44	6.60	6.42	0.19	2.94%
Voids in Mineral Aggregate	VMA	13.22	13.41	13.57	13.40	0.17	1.31%
Voids Filled with Asphalt	VFA	52.90	52.01	51.33	52.08	0.79	1.51%

Table 5 – Mix N4 Volumetric Data

Binder Percent (mix)	Pb	4.600
Binder Percent (agg)	Pb	4.822
Binder Spec. Gravity	Gb	1.038
Stone Bulk Spec. Gravity	Gsb	2.626
Percent Passing 0.075 mm	<0.075	4.602
Dust Proportion		1.145
Apparent Binder Content	Pba	0.581
Effective Binder Content	Pbe	4.019

Ndes	50

IDOT Low-Absorptive Conditioning Procedure

	Sample	N4-1	N4-2	N4-3	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.665				
Maximum Specific Gravity	Gmm		2.486				
Bulk Specific Gravity	Gmb	2.371	2.374	2.378	2.374	0.00	0.14%
Air Voids	Va	4.61	4.51	4.35	4.49	0.13	2.88%
Voids in Mineral Aggregate	VMA	13.85	13.76	13.62	13.74	0.12	0.85%
Voids Filled with Asphalt	VFA	66.74	67.21	68.05	67.33	0.67	0.99%

IDOT High-Absorptive Conditioning Procedure

	Sample	N4-4	N4-5	N4-6	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.677				
Maximum Specific Gravity	Gmm		2.496				
Bulk Specific Gravity	Gmb	2.369	2.369	2.369	2.369	0.00	0.00%
Air Voids	Va	5.09	5.09	5.10	5.09	0.00	0.09%
Voids in Mineral Aggregate	VMA	13.94	13.94	13.95	13.95	0.00	0.03%
Voids Filled with Asphalt	VFA	63.47	63.48	63.44	63.46	0.02	0.03%

SUPERPAVE Original Conditioning Procedure

	Sample	N4-7	N4-8	N4-9	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.680				
Maximum Specific Gravity	Gmm		2.498				
Bulk Specific Gravity	Gmb	2.364	2.366	2.371	2.367	0.00	0.15%
Air Voids	Va	5.36	5.28	5.08	5.24	0.14	2.71%
Voids in Mineral Aggregate	VMA	14.12	14.04	13.87	14.01	0.13	0.92%
Voids Filled with Asphalt	VFA	62.02	62.42	63.33	62.59	0.67	1.07%

Table 6 – Mix N5 Volumetric Data

Binder Percent (mix)	Pb	4.700			
Binder Percent (agg)	Pb	4.932			
Binder Spec. Gravity	Gb	1.018			
Stone Bulk Spec. Gravity	Gsb	2.639			
Percent Passing 0.075 mm	<0.075	3.864			
Dust Proportion		0.969			
Apparent Binder Content	Pba	0.713			
Effective Binder Content	Pbe	3.987		Ndes	90

IDOT Low-Absorptive Conditioning Procedure

	Sample	N5-1	N5-2	N5-3	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.689				
Maximum Specific Gravity	Gmm		2.496				
Bulk Specific Gravity	Gmb	2.400	2.402	2.408	2.404	0.00	0.18%
Air Voids	Va	3.85	3.75	3.51	3.70	0.17	4.70%
Voids in Mineral Aggregate	VMA	13.32	13.24	13.02	13.19	0.16	1.19%
Voids Filled with Asphalt	VFA	71.14	71.67	73.06	71.95	0.99	1.38%

IDOT High-Absorptive Conditioning Procedure

	Sample	N5-4	N5-5	N5-6	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.701				
Maximum Specific Gravity	Gmm		2.506				
Bulk Specific Gravity	Gmb	2.406	2.411	2.405	2.407	0.00	0.13%
Air Voids	Va	3.99	3.79	4.02	3.94	0.12	3.12%
Voids in Mineral Aggregate	VMA	13.11	12.93	13.14	13.06	0.11	0.85%
Voids Filled with Asphalt	VFA	69.57	70.65	69.38	69.87	0.69	0.98%

SUPERPAVE Original Conditioning Procedure

	Sample	N5-7	N5-8	N5-9	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.702				
Maximum Specific Gravity	Gmm		2.507				
Bulk Specific Gravity	Gmb	2.405	2.406	2.411	2.407	0.00	0.14%
Air Voids	Va	4.07	4.04	3.82	3.98	0.14	3.41%
Voids in Mineral Aggregate	VMA	13.15	13.12	12.92	13.06	0.12	0.94%
Voids Filled with Asphalt	VFA	69.02	69.19	70.41	69.54	0.76	1.09%

Table 7 – Mix N6 Volumetric Data

Binder Percent (mix)	Pb	5.300		
Binder Percent (agg)	Pb	5.597		
Binder Spec. Gravity	Gb	1.012		
Stone Bulk Spec. Gravity	Gsb	2.618		
Percent Passing 0.075 mm	<0.075	4.667		
Dust Proportion		0.964		
Apparent Binder Content	Pba	0.459		
Effective Binder Content	Pbe	4.841	Ndes	50

IDOT Low-Absorptive Conditioning Procedure

	Sample	N6-1	N6-2	N6-3	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.649				
Maximum Specific Gravity	Gmm		2.440				
Bulk Specific Gravity	Gmb	2.353	2.355	2.356	2.355	0.00	0.07%
Air Voids	Va	3.58	3.47	3.46	3.50	0.06	1.85%
Voids in Mineral Aggregate	VMA	14.89	14.79	14.78	14.82	0.06	0.39%
Voids Filled with Asphalt	VFA	75.98	76.55	76.60	76.38	0.35	0.45%

IDOT High-Absorptive Conditioning Procedure

	Sample	N6-4	N6-5	N6-6	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.672				
Maximum Specific Gravity	Gmm		2.458				
Bulk Specific Gravity	Gmb	2.360	2.361	2.355	2.359	0.00	0.13%
Air Voids	Va	3.98	3.97	4.19	4.05	0.12	3.05%
Voids in Mineral Aggregate	VMA	14.62	14.61	14.80	14.68	0.11	0.75%
Voids Filled with Asphalt	VFA	72.76	72.85	71.71	72.44	0.63	0.87%

SUPERPAVE Original Conditioning Procedure

	Sample	N6-7	N6-8	N6-9	Average	Std. Dev.	COV
Stone Effective Spec. Gravity	Gse		2.675				
Maximum Specific Gravity	Gmm		2.461				
Bulk Specific Gravity	Gmb	2.351	2.358	2.354	2.354	0.00	0.16%
Air Voids	Va	4.48	4.18	4.34	4.33	0.15	3.43%
Voids in Mineral Aggregate	VMA	14.96	14.69	14.84	14.83	0.13	0.89%
Voids Filled with Asphalt	VFA	70.06	71.55	70.73	70.78	0.74	1.05%

Table 8 – Mix N5M Volumetric Data

Binder Percent (mix)	Pb	4.700			
Binder Percent (agg)	Pb	4.932			
Binder Spec. Gravity	Gb	1.030			
Stone Bulk Spec. Gravity	Gsb	2.639			
Percent Passing 0.075 mm	<0.075	3.864			
Dust Proportion		0.966			
Apparent Binder Content	Pba	0.701			
Effective Binder Content	Pbe	3.999		Ndes	90

IDOT Low-Absorptive Conditioning Procedure

	Sample	N5M-1	N5M-2	N5M-3			
Stone Effective Spec. Gravity	Gse		2.687				
Maximum Specific Gravity	Gmm		2.498		Average	Std. Dev.	COV
Bulk Specific Gravity	Gmb	2.416	2.412	2.417	2.415	0.00	0.12%
Air Voids	Va	3.30	3.46	3.24	3.33	0.11	3.40%
Voids in Mineral Aggregate	VMA	12.76	12.90	12.70	12.79	0.10	0.80%
Voids Filled with Asphalt	VFA	74.14	73.19	74.50	73.95	0.68	0.91%

IDOT High-Absorptive Conditioning Procedure

	Sample	N5M-4	N5M-5	N5M-6			
Stone Effective Spec. Gravity	Gse		2.704				
Maximum Specific Gravity	Gmm		2.512		Average	Std. Dev.	COV
Bulk Specific Gravity	Gmb	2.414	2.404	2.407	2.408	0.01	0.22%
Air Voids	Va	3.90	4.30	4.19	4.13	0.21	5.03%
Voids in Mineral Aggregate	VMA	12.81	13.18	13.08	13.02	0.19	1.44%
Voids Filled with Asphalt	VFA	69.60	67.39	67.99	68.33	1.14	1.67%

SUPERPAVE Original Conditioning Procedure

	Sample	N5M-7	N5M-8	N5M-9			
Stone Effective Spec. Gravity	Gse		2.711				
Maximum Specific Gravity	Gmm		2.518		Average	Std. Dev.	COV
Bulk Specific Gravity	Gmb	2.392	2.393	2.402	2.396	0.01	0.23%
Air Voids	Va	5.02	4.95	4.61	4.86	0.22	4.50%
Voids in Mineral Aggregate	VMA	13.63	13.57	13.26	13.48	0.20	1.48%
Voids Filled with Asphalt	VFA	63.15	63.50	65.21	63.95	1.10	1.72%

N_{des} Analysis

Polymer-Modified Binder Mixes

As expected from the air void results, the polymer-modified mix N_{des} values exhibit higher dependence on conditioning time than do the neat binder mixes. This is demonstrated in Figure 4. Mix N1, a 90-gyration mix following IHA procedure, has mean back-calculated N_{des} values of 83, 101, and 118 for the ILA, IHA, and SHRP procedures, respectively. The coefficients of variation for this mix by procedure are: 2.20% for ILA, 4.03% for IHA, and 1.55% for SHRP. Mix N2 is a 105-gyration N_{des} by the ILA procedure and has calculated N_{des} values of 112, 155, and 188 for ILA, IHA, and SHRP procedures, respectively. The corresponding COVs are 2.14%, 2.03%, and 2.56%. Mix N3 is another 105 gyration, ILA design and has calculated N_{des} values of 117, 154, and 182 and COVs of 4.61%, 6.73%, and 5.07% for ILA, IHA, and SHRP, respectively. Mixture N5M is another 90-gyration mix designed using ILA procedures 76, 90, and 107 with COVs of 2.55%, 4.54%, and 5.17% for ILA, IHA, and SHRP, respectively. A summary of N_{des} values for all of the mixtures can be seen in Table 9.

Neat Binder Mixes

The mixes created using neat binders also have a trend of increasing N_{des} as conditioning time increased but it was not as pronounced. Mix N4 is a 50-gyration ILA design and has mean N_{des} values of 56, 63, and 66 with corresponding COVs of 1.92%, 1.62%, and 2.99% for ILA, IHA, and SHRP, respectively. After compaction to 90 gyrations, ILA designed mix N5 has calculated mean N_{des} values of 82, 86, and 87 and has COVs of 4.16%, 2.67%, and 2.91% for ILA, IHA, and SHRP, respectively. Mix N6 is another 50 gyration ILA design and obtained mean N_{des} values of 44, 49, and 53 and COVs of 1.92%, 2.74%, and 3.53%.

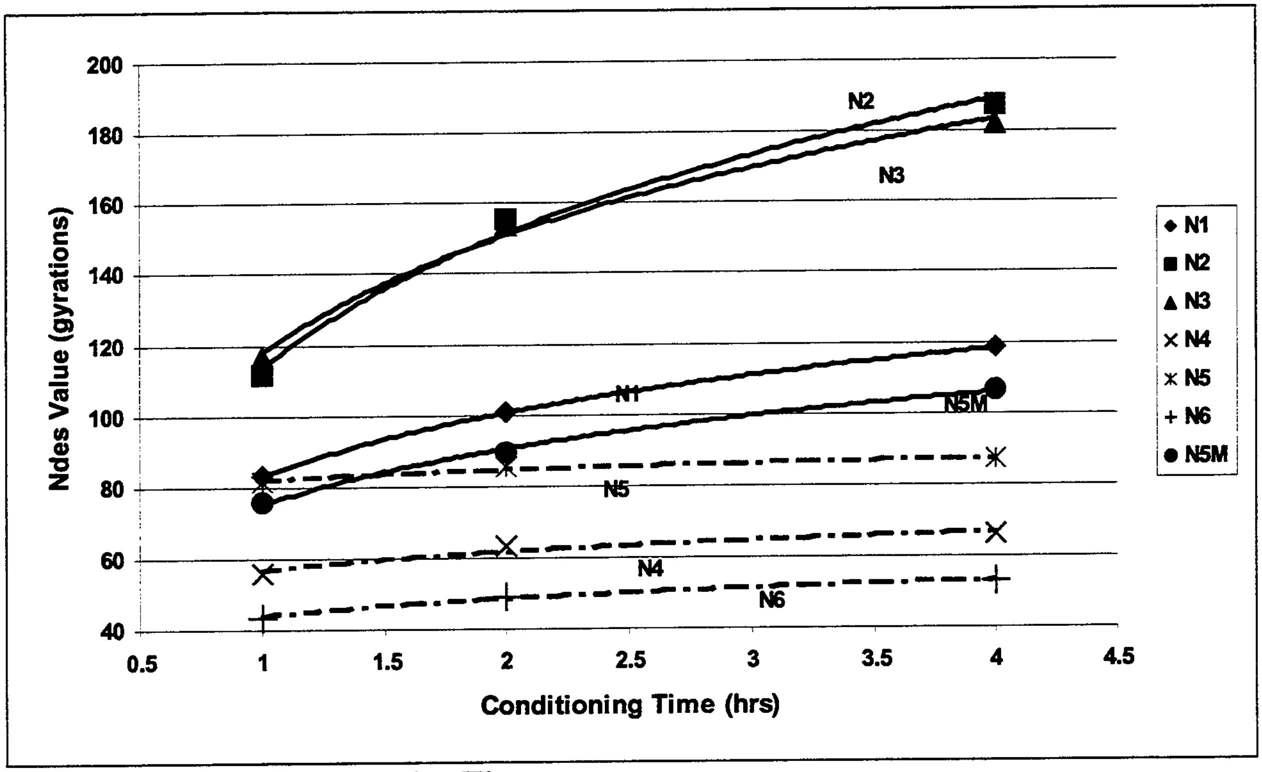

Figure 8 – Ndes vs. Conditioning Time

Plant Obtained/ATREL Reproduced Gmm Comparison

In addition to the volumetric testing results presented above, this report also includes a comparison of the Gmm results from the ATREL lab samples and the production plant mixture that was sampled. In order to limit the affects of aging on the field mix it was closely monitored during the reheating process. Once the mix was sufficiently warm, it was removed from the oven and split into Gmm samples. Shown in Table 10 are the results of the volumetric testing. The ATREL column contains the maximum specific gravity obtained on the lab prepared specimens following the appropriate conditioning procedure for a particular mix. With the exception of N1, which was designed using IHA specification, all of the HMA samples were conditioned following ILA protocol. The Plant column contains the average G_{mm} results for the plant obtained mix after reheating. Note that small deviations in AC content can greatly affect the G_{mm} results.

Table 9 – Results of Ndes Back-calculation

ILA Conditioning Procedure						
Mix	**NX-1**	**NX-2**	**NX-3**	**Average**	**Std. Dev.**	**COV**
N1	85	82	--	**83**	1.83	2.20%
N2	111	110	114	**112**	2.39	2.14%
N3	122	111	117	**117**	5.38	4.61%
N4	57	56	55	**56**	1.07	1.92%
N5	84	82	78	**82**	3.39	4.16%
N6	45	43	43	**44**	0.84	1.92%
N5M	74	78	75	**76**	1.93	2.55%
IHA Conditioning Procedure						
Mix	**NX-4**	**NX-5**	**NX-6**	**Average**	**Std. Dev.**	**COV**
N1	96	104	101	**101**	4.06	4.03%
N2	152	158	156	**155**	3.16	2.03%
N3	142	160	160	**154**	10.37	6.73%
N4	62	64	64	**63**	1.03	1.62%
N5	87	83	87	**86**	2.29	2.67%
N6	49	49	51	**49**	1.35	2.74%
N5M	85	93	91	**90**	4.07	4.54%
Original SHRP Conditioning Procedure						
Mix	**NX-7**	**NX-8**	**NX-9**	**Average**	**Std. Dev.**	**COV**
N1	116	120	119	**118**	1.83	1.55%
N2	190	182	191	**188**	4.81	2.56%
N3	172	184	191	**182**	9.23	5.07%
N4	68	66	64	**66**	1.98	2.99%
N5	89	88	84	**87**	2.53	2.91%
N6	55	51	53	**53**	1.87	3.53%
N5M	111	108	100	**107**	5.51	5.17%

Table 10 – ATREL/Plant Gmm Comparison

Mix	ATREL	Plant
N1	2.571	2.562
N2	2.466	2.513
N3	2.512	2.537
N4	2.486	2.504
N5	2.496	2.508
N6	2.440	2.452
N5M	2.498	--

STATISITICAL ANALYSIS

A statistical analysis was performed on the percent air voids and the N_{des} values for all of the mixtures to determine the significance of the different conditioning procedures. The differences in conditioning were quantified using Fisher's Least Significant Difference (LSD) test. This test performs all possible t-tests and is less protective in terms of the experimentwise error rate, however the data collected during this study falls within all precision and bias statements outlined by the Illinois DOT and the AASHTO standards so experimentwise error is not a concern. For any two aging procedures to be considered statistically the same, the difference between mean air voids for that mixes would need to be smaller than the LSD. The test was performed with a significance level of 0.05.

In order to perform the Fisher LSD procedure the following assumptions must be met: samples must be independent and random, come from normal populations, and have common variance. All these requirements were met within the experimental design. The results of the statistical tests are provided in analysis of variance (ANOVA) and LSD tables. Similar conditioning procedures have the same T-Grouping letter in the LSD tables. Note that if the ILA and IHA results are different, then it follows that ILA and SHRP must be different since the differences between means is even greater.

Volumetrics

Polymer-Modified Binder Mixtures

The differences in the air voids for all the polymer-modified mixtures were found to be statistically significant. For mix N1 the LSD was determined to be 0.25 and the difference between means is 0.68 for the ILA and IHA procedures and 0.76 for the IHA and SHRP procedures. For N2 the LSD was calculated at 0.12, however the difference between ILA and

IHA is 1.41 and the difference between IHA and SHRP is 0.72. N3 had an LSD of 0.49, nearly one-half of a 1 percent air voids, but the difference between the means for all the procedures is still larger than this. Mix N5M has an LSD of 0.37 but again the air voids differences are still too large to consider any of them equal. The ANOVA and LSD results in Tables 11 through 24 summarize the statistical testing performed on the air voids.

Neat Binder Mixtures

For the mixes that contain neat binders, the statistical testing has varied results. The results of mix N4, which has an LSD of 2.25, show that there is no significant difference between the IHA and SHRP conditioning procedures but there does exist a statistical difference between ILA and IHA. This substantiates the ETG recommendation that there is no distinction between two hours and four hours of conditioning for low absorptive aggregate(1). Mix N5 has an LSD of 0.29, demonstrating there is no statistical difference between any of the aging procedures, and again validates the ETG recommendation. Mix N6 has results similar to the polymer-modified mixtures. The LSD for N6 is 0.24 and is smaller than any of the mean differences; consequently, all the conditioning procedures are statistically different.

Table 11 – N1 Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.55	1.28	135.25	0.0001
Error	5	0.05	0.0094		
Corrected Total	7	2.6			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.982	2.55	1.28			

Table 12 – N1 Air Voids LSD

alpha = 0.05	df = 5	MSE=0.0094	
Critical T value=2.57			
Least Significant Difference =0.22			
T Grouping	Mean	N	Aging
A	5.42	3	SHRP
B	4.66	3	IHA
C	3.98	2	ILA

Table 13 – N2 Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7.08	3.54	974.52	0.0001
Error	6	0.02	0.0036		
Corrected Total	8	7.1			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.997	1.07	0.06			

Table 14 – N2 Air Voids LSD

alpha = 0.05	df = 6	MSE=0.0036	
Critical T value=2.45			
Least Significant Difference =7.11			
T Grouping	Mean	N	Aging
A	6.57	3	SHRP
B	5.84	3	IHA
C	4.44	3	ILA

Table 15 – N3 Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5.66	2.83	47.28	0.0002
Error	6	0.36	0.0598		
Corrected Total	8	6.02			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.940	4.39	0.24			

Table 16 – N3 Air Voids LSD

alpha = 0.05	df = 6	MSE=0.0598	
Critical T value=2.45			
Least Significant Difference =0.49			
T Grouping	Mean	N	Aging
A	6.42	3	SHRP
B	5.77	3	IHA
C	4.51	3	ILA

Table 17 – N4 Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.94	0.474	37.39	0.0004
Error	6	0.8	0.0127		
Corrected Total	8	1.02			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.926	2.28	0.11			

Table 18 – N4 Air Voids LSD

alpha = 0.05	df = 6	MSE=0.0127	
Critical T value=2.45			
Least Significant Difference =0.23			
T Grouping	Mean	N	Aging
A	5.24	3	SHRP
A	5.09	3	IHA
B	4.49	2	ILA

Table 19 – N5 Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.13	0.065	3	0.1252
Error	6	0.13	0.0216		
Corrected Total	8	0.26			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.500	3.80	0.15			

Table 20 – N5 Air Voids LSD

alpha = 0.05	df = 6	MSE=0.0216	
Critical T value=2.45			
Least Significant Difference =0.29			
T Grouping	Mean	N	Aging
A	3.98	3	SHRP
A	3.93	3	IHA
A	3.70	3	ILA

Table 21 – N6 Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.07	0.533	37.72	0.0004
Error	6	0.08	0.014		
Corrected Total	8	1.15			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.926	3.00	0.12			

Table 22 – N6 Air Voids LSD

alpha = 0.05	df = 6	MSE=0.0140	
Critical T value=2.45			
Least Significant Difference =0.24			
T Grouping	Mean	N	Aging
A	4.33	3	SHRP
B	4.05	3	IHA
C	3.50	3	ILA

Table 23 – N5M Air Voids ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.5	1.749	50.59	0.0002
Error	6	0.21	0.0346		
Corrected Total	8	3.71			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.944	4.53	0.19			

Table 24 – N5M Air Voids LSD

alpha = 0.05	df = 6	MSE=0.0346	
Critical T value=2.45			
Least Significant Difference =0.37			
T Grouping	Mean	N	Aging
A	4.86	3	SHRP
B	4.13	3	IHA
C	3.33	3	ILA

Calculated N_{des}

Since the back-calculated N_{des} values are dependent on the air voids, it is expected that the results of the N_{des} statistical testing will be the same. This was the case for every mix except N5. For this mix the results show that, for N_{des}, the ILA and IHA procedures are the same and that the IHA and the SHRP procedures are the same, but that the ILA and SHRP procedures are different. In the air void statistical results it was shown there were no statistical differences between any of these conditioning methods. This discrepancy can be explained by examining the LSD value for N_{des}. The N_{des} LSD for N5 is 5.37 and the difference between the ILA and SHRP means is 5.67. With a 0.3 gyration difference between these values, it is felt that rounding errors in the back-calculation process are the cause of this incongruity, and there really is no statistical difference between these procedures. The statistical results from the N_{des} testing are summarized in Tables 25 through 38.

Table 25 – N1 N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1466.54	733.27	109.99	0.0001
Error	5	33.33	6.67		
Corrected Total	7	1499.88			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.978	2.49	2.58			

Table 26 – N1 N_{des} LSD

alpha = 0.05	df = 5	MSE=6.6700	
Critical T value=2.57			
Least Significant Difference =5.85			
T Grouping	Mean	N	Aging
A	119.33	3	SHRP
B	100.33	3	IHA
C	85.00	2	ILA

Table 27 – N2 N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	8728.22	4365.11	344.54	0.0001
Error	6	76	12.67		
Corrected Total	8	8804.22			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.991	2.35	3.56			

Table 28 – N2 N_{des} LSD

alpha = 0.05	df = 6	MSE=12.6670	
Critical T value=2.45			
Least Significant Difference =7.11			
T Grouping	Mean	N	Aging
A	187.67	3	SHRP
B	155.33	3	IHA
C	111.67	3	ILA

Table 29 – N3 N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	6508.67	3254.33	42.33	0.0003
Error	6	461.33	76.89		
Corrected Total	8	6970			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.934	5.81	8.77			

Table 30 – N3 N_{des} LSD

alpha = 0.05	df = 6	MSE=76.8900	
Critical T value=2.45			
Least Significant Difference =17.52			
T Grouping	Mean	N	Aging
A	182.33	3	SHRP
B	154.00	3	IHA
C	116.67	3	ILA

Table 31 – N4 N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	160.89	80.44	38.11	0.0004
Error	6	12.67	2.11		
Corrected Total	8	173.56			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.927	2.35	1.45			

Table 32 – N4 N_{des} LSD

alpha = 0.05	df = 6	MSE=2.1110	
Critical T value=2.45			
Least Significant Difference =2.90			
T Grouping	Mean	N	Aging
A	66.00	3	SHRP
A	63.33	3	IHA
B	56.00	2	ILA

Table 33 – N5 N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	52.67	26.33	3.65	0.092
Error	6	43.33	7.22		
Corrected Total	8	96			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.549	3.17	2.69			

Table 34 – N5 N_{des} LSD

alpha = 0.05	df = 6	MSE=7.2200	
Critical T value=2.45			
Least Significant Difference =5.37			
T Grouping	Mean	N	Aging
A	87.00	3	SHRP
A B	85.67	3	IHA
B	81.33	3	ILA

Table 35 – N6 N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	134.22	67.11	30.2	0.007
Error	6	13.33	2.22		
Corrected Total	8	147.56			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.910	3.06	1.49			

Table 36 – N6 N_{des} LSD

alpha = 0.05	df = 6	MSE=2.2200	
Critical T value=2.45			
Least Significant Difference =2.98			
T Grouping	Mean	N	Aging
A	53.00	3	SHRP
B	49.67	3	IHA
C	43.67	3	ILA

Table 37 – N5M N_{des} ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1414.22	707.11	39.28	0.0004
Error	6	108	18		
Corrected Total	8	1522.22			
R-Square	C.V.	Root MSE	alpha = 0.05		
0.929	4.69	4.24			

Table 38 – N5M N_{des} LSD

alpha = 0.05	df = 6	MSE=18.0000	
Critical T value=2.45			
Least Significant Difference =8.48			
T Grouping	Mean	N	Aging
A	106.33	3	SHRP
B	89.67	3	IHA
C	75.67	3	ILA

INTERPRETATION OF RESULTS

Based on the statistical data presented in the previous section it can be seen that polymer-modified mixes age differently in the laboratory than mixes created using neat binders. However, the statistical comparison testing is highly influenced by the variations in the test results. To put it another way, the higher the COV is for the air voids in a mix, the larger the LSD is for that mix. Comparisons of the precision and bias statements for the volumetric testing standards and the results acquired in this study demonstrate that the obtained volumetric test results are much tighter than required by the standards. Based on the results of AMRL and IDOT Round Robin testing, samples produced and tested at ATREL consistently have much smaller deviations than what is allowed by AASHTO precision statements for volumetric testing. This being the case, the small amounts of variation in the volumetric results influenced the statistical testing and need to be addressed.

To illustrate this, consider the precision statement for AASHTO T 166-93 "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens," which allows for deviations of 0.020 by a single operator for a duplicate measurement. For a typical G_{mm} value of 2.500, this allowance can result in an air void range of approximately 0.80 percent. For a 0.80 percent range in air voids, the N_{des} has an equally large range of values for a sample that would be acceptable. For the 50 gyration mixes the range would be 9 gyrations, for the 90 gyration mixes the range is 20 gyrations, and for the 105 gyration mixes the range is 38 gyrations. These ranges are larger than all the LSD values obtained from the statistical testing.

The overall trend in increasing the conditioning time is to have increased air voids and N_{des} values for a mix. Based on volumetric properties, the polymer-modified mixes are considerably more affected by increased conditioning time than are the neat binder mixes. It appears that this difference is the result of the polymers in the binder and not the increased conditioning temperature. For the neat binder mixes the results were varied, but based on the testing performed in this study it cannot be concluded whether N_{des} level or nominal max aggregate size is the cause of the variation, or if it is a result of having different aggregate and asphalt binder sources.

Polymer-Modified Binder Mixtures

While statistically all the conditioning procedures for the polymer-modified mixes are different, an evaluation based on the 0.80% air void range modifies this conclusion. For mixes N1 and N5M, this examination shows that the ILA and IHA procedures are comparable and that the IHA and SHRP procedures are also comparable. The difference between the ILA and SHRP air voids are larger than 0.80 percent, so they cannot be considered the same. For N2 and N3 the only change is that now the IHA and SHRP procedures are equivalent. These new results agree with the mixtures ETG that there is no difference between 2 hours of aging and 4 hours of aging for low-absorptive aggregates. Furthermore, it shows this for polymer-modified binders conditioned at compaction temperature and not 135 °C. The results of this new analysis can be seen in Tables 39 though 45.

Neat Binder Mixes

For some of the neat binder mixes it was shown statistically there is no difference between the different conditioning procedures. For N4 it was initially shown that there were no differences between the IHA and SHRP procedures, but using the increased range of 0.80% allows all the procedures to be considered equal. For N5 the statistical analysis showed no difference between any of the conditioning procedures, and since the 0.80% range is larger than the LSD of 0.29% the same conclusion is met. Based off the statistical LSD test for N6, none of the conditioning procedures is comparable but the reexamination shows that the ILA and IHA procedures are similar and the IHA and SHRP methods are also similar. Upon closer inspection the difference between means for the ILA and SHRP procedures is 0.83%, only 0.03% air voids from being comparable.

Table 39 – N1 LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	5.42	A	A
IHA	4.66	B	A B
ILA	3.98	C	B

Table 40 – N2 LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	6.57	A	A
IHA	5.84	B	A
ILA	4.44	C	B

Table 41 – N3 LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	6.42	A	A
IHA	5.77	B	A
ILA	4.51	C	B

Table 42 – N4 LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	5.24	A	A
IHA	5.09	A	A
ILA	4.49	B	A

Table 43 – N5 LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	3.98	A	A
IHA	3.93	A	A
ILA	3.70	A	A

Table 44 – N6 LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	4.33	A	A
IHA	4.05	B	A B
ILA	3.50	C	B

Table 45 – N5M LSD/Precision Comparison

Aging	Mean	LSD Grouping	Precision
SHRP	4.86	A	A
IHA	4.13	B	A B
ILA	3.33	C	B

CONCLUSIONS

Conclusions

- Increased conditioning time has a greater impact on the volumetric properties of polymer-modified binder mixes than on neat binder mixes.
- The presence of polymers in the binder appears to have greater effect than the higher temperatures used for conditioning polymer-modified HMA
- For polymer-modified binder mixes Illinois Modified AASHTO PP 2-99 and the standard AASHTO PP 2-99 do not produce similar mixes
- For neat binder mixes Illinois Modified AASHTO PP 2-99 and the standard AASHTO PP 2-99 do produce similar mixes.
- Samples conditioned at the compaction temperature are similar to samples conditioned at 135 °C.

Future Research

This study appears to demonstrate that the presence of polymers in the asphalt binder appear to cause increased short-term aging on HMA. Further investigation is warranted to determine if this is in fact the case.

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