Hot Mix Asphalt Research Investigation For Connecticut: Part A – Reduction in the Number Of Superpave Mix Design Levels

Prepared by: James Mahoney, Eric Jackson
Scott Zinke, John DaDalt

Report Number CT-2250-1-08-11
July 31, 2009

SPR 2250 – Part A

Connecticut Advanced Pavement Laboratory
Connecticut Transportation Institute
University of Connecticut

Prepared for:
Connecticut Department of Transportation

James A. Fallon, P.E.
Manager of Facilities and Transit
Bureau of Engineering and Construction

Disclaimer

This report does not constitute a standard, specification or regulation. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Connecticut Department of Transportation, Federal Highway Administration or the University of Connecticut.

Acknowledgements

This report was prepared by the University of Connecticut, in cooperation with the Connecticut Department of Transportation and the United States Department of Transportation, Federal Highway Administration. The opinions, findings and conclusions expressed in the publication are those of the author(s) and not necessarily those of the Connecticut Department of Transportation or the Federal Highway Administration. This publication is based upon publicly supported research and is copyrighted. It may be reproduced in part or in full, but it is requested that there be customary crediting of the source.

The research team would like to thank all those involved with this research without their support this research would not have been possible. The suppliers who contributed mix to this study are:

AEN – Franklin;
O & G – Bridgeport;
O & G – Torrington;
O & G – Woodbury;
Suzio – Meriden;
Tilcon – North Branford; and,
Tilcon – Wallingford.

The research team would also like to thank the Connecticut Department of Transportation as well as the Federal Highway Administration for their support of this research.

Metric Conversion Factor Sheet

SI CONVERSION FACTORS				
SYMBOL	GIVEN	MULTIPLY BY	CONVERT TO	SYMBOL
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	NOTE: volumes greater than 1000L shall be shown in m^3			
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or metric ton)	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C + 32	Farenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

Technical Report Documentation Page

1. Report No. CT-2250-1-08-11	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Hot Mix Asphalt Research Investigation for Connecticut: Part A - Reduction in the Number of Superpave Mix Design Levels		5. Report Date July 31, 2009 6. Performing Organization Code SPR-2250
7. Author(s) James Mahoney, Eric Jackson, Scott Zinke, John DaDalt		8. Performing Organization Report No. CAPLAB 6-2009
9. Performing Organization Name and Address University of Connecticut Connecticut Advanced Pavement Laboratory Connecticut Transportation Institute 179 Middle Turnpike, U-202 Storrs, Connecticut 06269-5202		10 Work Unit No. (TRIS) 11. Contract or Grant No. CT Study No. SPR-2250
12. Sponsoring Agency Name and Address Connecticut Department of Transportation 2800 Berlin Turnpike Newington, CT 06131-7546		13. Type of Report and Period Covered Final Report, SPR 2250, Part A 14. Sponsoring Agency Code SPR-2250

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract
This research is the first in a series of investigated topics surrounding hot mix asphalt in Connecticut. Currently there are at least 12 different mix designs that need to be developed by producers of HMA with four traffic levels and three nominal maximum aggregate sizes. This can cause undesirable delays in production when plants switch between mixes to accommodate customers' orders. This research focuses on the impacts of reducing the number of mix designs that are necessary without compromising the long-term integrity and performance of pavement. Testing took place in the laboratory utilizing HMA performance testing equipment. Rut depth differences for design Levels 2, 3 and 4 were insignificant, showing Superpave mixes in Connecticut are quite capable of withstanding loading from traffic without the use of design Level 4. Level 3 with an elastomeric polymer modified binder may be substituted for design Level 4 in areas with rutting problems. See report for other recommendations.

17. Key Words Asphalt Pavements, Mix Design, Nominal Maximum Aggregate, Asphalt Pavement Analyzer, SuperPave	18.Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161. The report is available on-line from National Transportation Library at http://ntl.bts.gov.

19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	21. Price
Form DOT F 1700.7 (8-72)	Reproduction of completed page authorized		

Table of Contents

List of Figures

List of Tables

Background

The Superpave mix design system was developed as part of the Strategic Highway Research Program during the early 1990's. One of the primary foci of the Superpave mix design system was to eliminate the problem of permanent deformation of Hot-Mix Asphalt (HMA) pavements as many transportation agencies were having problems with permanent deformation issues. This permanent deformation was most commonly observed as rutting in the wheel paths. The Superpave mix design system stresses the importance of stone-on-stone contact to allow the pavement to support the traffic loadings without actually deforming.

In order to address this problem, the Superpave mix design system increased the compactive effort applied to the HMA mixture in the Superpave gyratory as the anticipated traffic loadings would also increase. The current Superpave mix design methodology utilizes four distinct traffic level bands corresponding to these traffic loadings. The effect of these four different traffic levels is that each HMA production facility is required to have four different Superpave mix designs for each nominal maximum size of HMA they produce. For each HMA plant, this typically requires a minimum of twelve different Superpave mix designs. Prior to the invention and adoption of the Superpave system, there was only a need for HMA plants to accommodate three different mix designs: Class 1, Class 2 and Class 4.

It is difficult for HMA producers to change between mixes with different aggregate blends (structures) in a timely manner to meet their customers' needs. In response to HMA producers needing at least twelve different Superpave mix designs, HMA producers have tried to develop their mix designs for the four different traffic levels with minimal differences to the aggregate structure between the different traffic levels. This has resulted in some cases of the exact same aggregate structure being used for two different traffic levels with the only difference between the levels being the amount of asphalt binder being added to the mixture. Typically, the higher traffic level mixes have a lower asphalt binder content. It is generally accepted that as the asphalt content of HMA mixtures decreases, the pavement is less durable as it pertains to environmental damage.

With different traffic level mixes having the same, or similar, aggregate structure and decreasing asphalt binder contents as the traffic levels increase, there is some concern that the higher traffic level Superpave mixes may not provide any significant increase in the pavement's ability to resist permanent deformation, and may actually decrease its ability to resist environmental damage, thus, ultimately decreasing the actual service life of the pavement structure.

Objective

The objective of this research was to examine the potential impact of reducing the number of traffic levels used in the Superpave mix design methodology. The research examined the potential impact on the ability of HMA to resist permanent deformation as well as environmental damage from the interaction of water and the asphalt binder and aggregate bond. These examinations were conducted with the use of HMA mix performance testing equipment in the laboratory.

Literature Review and Survey of Regional Mix Design Usage

The origins of Superpave have been attributed to a special report published by the Transportation Research Board in 1984 (TRB, 1984). In 1986, the American Association of State Highway and Transportation Officials (AASHTO) recommended research that would broaden the focus of asphalt research to include mixture design methods (TRB, 2004). In 1987, the Strategic Highway Research Program (SHRP) was founded. The goal of the SHRP was to combat the deteriorating conditions of the nation's highways and improve their performance, durability, safety, and efficiency by developing new testing and evaluation methods (Halladay, 1998). The first Superpave pavement was constructed on July 8, 1992, in Wisconsin and, by 2005, a survey conducted by the TRB Superpave committee indicated that all states had accepted and adopted the Superpave binder specifications (TRB, 2005). A majority of the states (36) had adopted the mix design specifications (TRB, 2005).

These standards and specifications laid the groundwork for a uniformed approach to asphalt pavement design and testing. However, as with most engineering designs, standards are not static and need constant revision through research to address unacceptable performance over time. Revisions to standards and practice, work to optimize lifespan and durability of the engineered product. This is also true with Superpave which has undergone noticeable evolution since the first specifications were released. Since 1995, research findings have resulted in 21 full standard specifications, six currently provisional standards, and eight future standards that are now being developed (TRB 2005). The Superpave system was designed to address two pavement distresses: permanent deformation, which results from inadequate shear strength in the asphalt mix and is the driving focus of this research; and low temperature cracking, which is generated when an asphalt pavement shrinks and the tensile stress exceeds the tensile strength.

In an effort to understand how other states have addressed these issues, states in the northeast were surveyed as to their restrictions on asphalt content and the mix design levels currently used. Table 1 contains the results of this survey. Of the five states which replied to the survey three do not have requirements for minimum asphalt content. Furthermore, New Hampshire only has requirements for its 12.5 mm wearing course. When inquiring about Superpave traffic levels used for determining the number of gyrations in the mix design, the answers varied greatly from state to state.

Table1 - Regional HMA Mix Design Survey

	Does your State Have Requirements for Minimum Asphalt Content for Superpave Mixes?	Is Your State Still Using the 4 Superpave Traffic Levels for Determining the Number of Gyrations?
New York	Yes[1]	Yes, but with modified design gyration levels
New Jersey	No	No, Dropped highest traffic level
Vermont	No	Yes, but currently investigating new gyration levels
Maine	No	liberal interpretation of the ESAL requirements (note: there are few highways with higher ESAL levels in Maine)
New Hampshire	Only for 12.5mm wearing course: 5.8% for 50 gyration, 5.5% for 75 gyration mix designs	No. NHDOT only uses two gyration levels (50 and 75)

1. > 5.8% for a 9.5 mm design, >5.2% for a 12.5 mm, >4.5% for a 19.0 mm design, >4.2% for a 25.0 mm design, >3.7% for a 37.5 mm design.

The results from the survey conducted above indicate the Superpave system is being tailored to fit the needs of each state. Furthermore, a literature search on modifications or reductions to the Superpave mix design levels generated limited results. In an effort to obtain a better idea of how other states are modifying their Superpave mix designs, a search was conducted to obtain mix design guidelines from various states throughout the US. The results indicate there are states using anywhere from two to five different traffic levels for their mix designs. For example, Kentucky uses three levels while the Washington State specifications include all five Equivelant Single Axle Loads (ESAL) classes. The results of this research will make recommendations on whether Connecticut can reduce the number of Superpave mix design levels to reduce strain on producers and ensure adequate binder content without sacrificing pavement performance.

Methodology

The primary testing for this research was conducted using the Asphalt Pavement Analyzer (APA). The APA is capable of conducting both AASHTO TP 63-07, *Determining Rutting Susceptibility of Hot-Mix Asphalt Using the Asphalt Pavement Analyzer (APA),* and AASHTO T 324-04, *Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt*. The APA test looks at the tendency for the dry HMA to deform plastically at elevated temperatures and loading. The APA test utilizes a rubber hose with compressed air lying on the surface of the specimens and a vertically loaded steel wheel travels back and forth across the rubber hose. The Hamburg test is conducted with the HMA specimens completely submerged in water at an elevated temperature and a vertically loaded steel wheel is forced across the surface of the specimens. Unlike the APA test, the Hamburg test wheels are in direct contact with the HMA specimens. The Hamburg test is particularly good at determining the effect environmental damage caused by water on HMA. This occurs because the specimen is completely submerged in the water and the steel wheel travelling back and forth generates pore pressure with the water in the specimen. This pore pressure will potentially cause the asphalt binder to lose its bond with the aggregate and therefore deform much more than mixtures where the bond between the aggregate and asphalt is stronger.

It is important to note that neither the APA nor the Hamburg tests have specific values for determining whether a material passes or fails. The data must be interpreted as more of a comparison between the different materials. Some states have established pass/fail criteria but, those are based upon a calibration performed in their state conducted by comparing test data and field observations. That level of calibration has not been performed in Connecticut.

The research team identified seven different HMA plants that supply Superpave mixes to ConnDOT and represent wide variety of HMA producers. Mix designs for each of the selected HMA plants were obtained for at least two different 0.5 inch (12.5 mm) Superpave mixes. The actual mix designs are contained in Appendix A. The research team obtained samples of each of the component aggregates and any RAP used in the mix designs. The asphalt binder used for all of the mixes was PG 64-28 from a single asphalt binder supplier.

The Superpave mixes used for this research were obtained from the following HMA production facilities:

AEN – Franklin;
O & G – Bridgeport;
O & G – Torrington;
O & G – Woodbury;
Suzio – Meriden;
Tilcon – North Branford; and,
Tilcon – Wallingford.

The research team fabricated the Superpave mixes using the mix designs provided for each of the plants and traffic levels. The research team did compare the asphalt binder content for the provided Superpave mix designs against the minimum asphalt contents required by ConnDOT. When the mix design value was below the required ConnDOT minimum asphalt content, the asphalt binder was adjusted to meet the minimum asphalt content values.

After mixing the HMA, gyratory specimens were fabricated in accordance with AASHTO TP 63-07, *Determining Rutting Susceptibility of Hot-Mix Asphalt Using the Asphalt Pavement Analyzer (APA),* and AASHTO T 324-04, *Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt*. There were two deviations from the AASHTO specifications associated with these tests. The first deviation occurred with the fabrication of the test specimens, the Hamburg procedure requires specimens with air voids of 7.0 ± 1.0 percent while the APA procedure requires air void contents of 7.0 ± 0.5 percent. All specimens for both tests were fabricated to the 7.0 ± 1.0 percent air voids. The second deviation from the AASHTO protocol occurred with the Hamburg procedure. The specimens used for testing in the Hamburg procedure were secured together using the plastic specimen mounts provided by the equipment manufacturer rather than Plaster-of-Paris. The AASHTO standard does allow for other mounting materials to be used, but specifically state the acceptability of the plastic specimen mounts. All other testing of the specimens was done in accordance with the applicable AASHTO standard. The CAP Lab performed maximum theoretical specific gravity testing on all lab made HMA to ensure the air void calculations were accurate.

The APA test was performed using 8,000 cycles for the test and the specimens were at the high temperature grade for the asphalt binder PG grade, 64° C. The Hamburg test was targeting 20,000 cycles for each test at 45° C. As the Hamburg test is extremely destructive, many of the tests did not complete all 20,000 cycles. The test equipment is designed to cease the test once a specified amount of deformation has occurred. The AASHTO standard for the Hamburg test does not specify the test temperature and from previous experience, 45° C was determined to be a reasonable temperature for our materials. Previous experiments at 50° C showed a very rapid degradation of the test specimens.

It should be noted that the results as well as the mix designs for the mix from each plant have been blinded.

For both the APA and Hamburg tests three replicates were tested and the average values were used in the analysis. ASTM E178 was used to test for outliers in the group of 3 replicates. There were five outliers removed as part of the ASTM outlier evaluation.

Results and Analysis

The results for the testing of the materials from the seven HMA production facilities can be found in Table 2.

Table 2 – Summary of Test Results for APA and Hamburg Testing

	Average APA Rut Depth, mm	Average Number of Hamburg Cycles	Average Hamburg Rut Depth, mm
Plant A - Level 3	4.247	20000	7.77
Plant A - Level 4	3.255	15046	8.53
Plant B - Level 2	3.232	20000	10.30
Plant B - Level 3	2.681	15150	15.36
Plant B - Level 4	3.73	20000	10.80
Plant C - Level 1	4.634	9939	18.35
Plant C - Level 2	4.709	4538	17.31
Plant D - Level 3	3.595	9771	17.68
Plant D - Level 4	4.168	11968	16.01
Plant E - Level 2	3.923	5555	16.90
Plant E - Level 3	3.002	4278	10.24
Plant F - Level 2	3.18	9355	15.32
Plant F - Level 3	3.156	11910	17.62
Plant F - Level 4	4.085	5398	18.30
Plant G - Level 2	4.606	4885	14.57
Plant G - Level 3	4.527	5085	17.86

Figures 1, 3 and 5 show the average results when all of the similar traffic levels are grouped together. Since only one test was performed on Level 1 material, it was excluded from the plots. The data in Figure 1 shows a reduction of the APA rut depth when comparing the Level 2 and 3 mixes. This reduction is not very large, approximately 0.4 mm. The increase of rut depth between Level 3 and 4 is again not very large, approximately 0.3 mm. While this general trend held as part of the overall macroscopic data set, there were some exceptions that did not hold this trend. Figure 2 shows the specific APA data by plant and mix level.

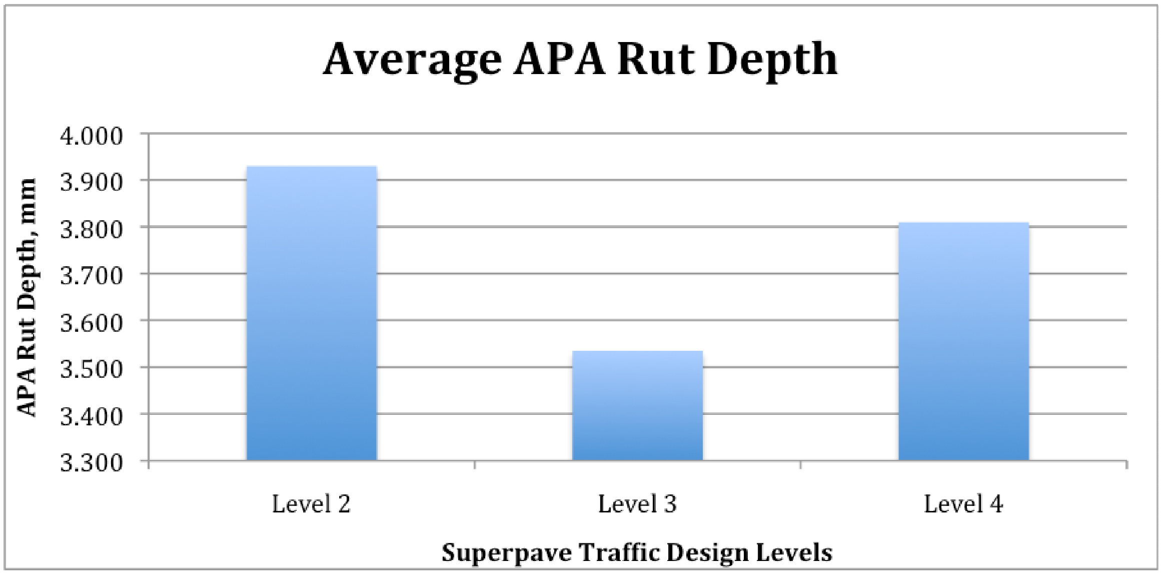

Figure 1 – Average Rut Depth APA

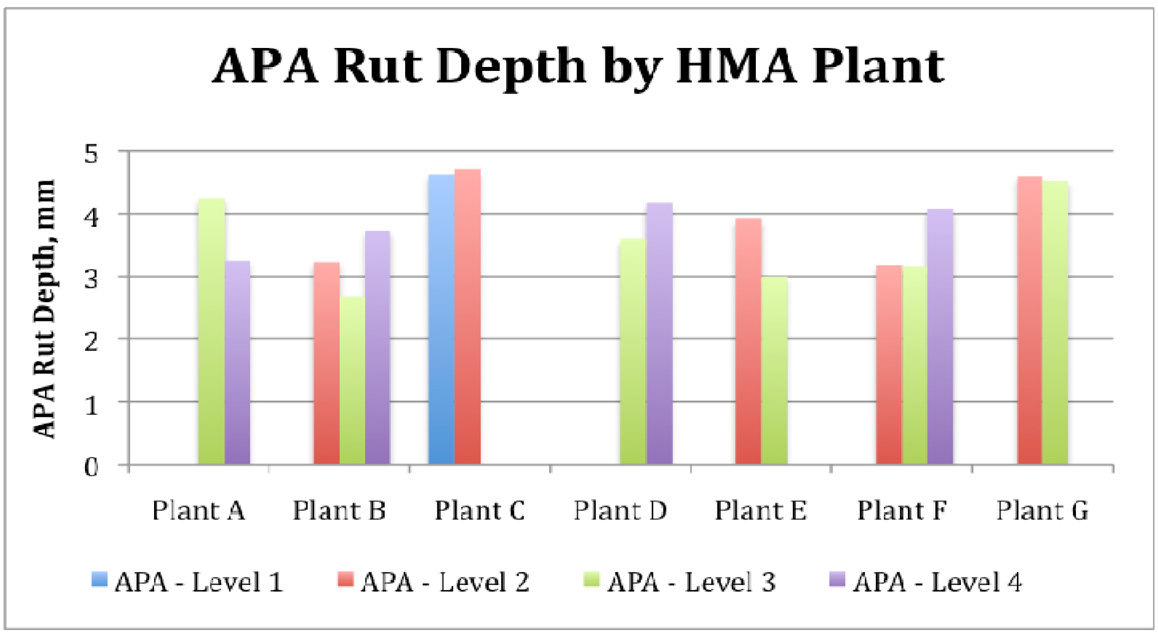

Figure 2 – APA Rut Depth by Traffic Level and HMA Plant

Figure 3 shows that the number of cycles conducted in the Hamburg test does generally increase as the Superpave Level increases. This is generally what would be expected. Again, this is the overall trend for these mixes and there are some isolated instances where this overall trend did not prove true when comparing different level mixes from the same plant. Figure 4 shows the individual results for each mix level and traffic level.

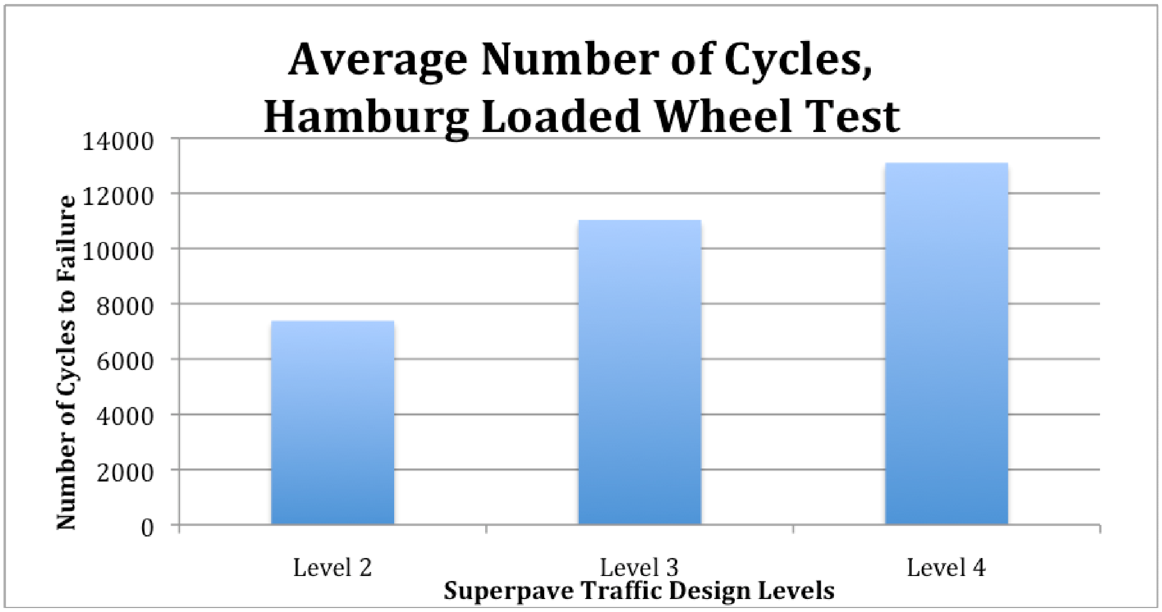

Figure 3 – Average Number of Cycles on Hamburg Loaded Wheel Tester

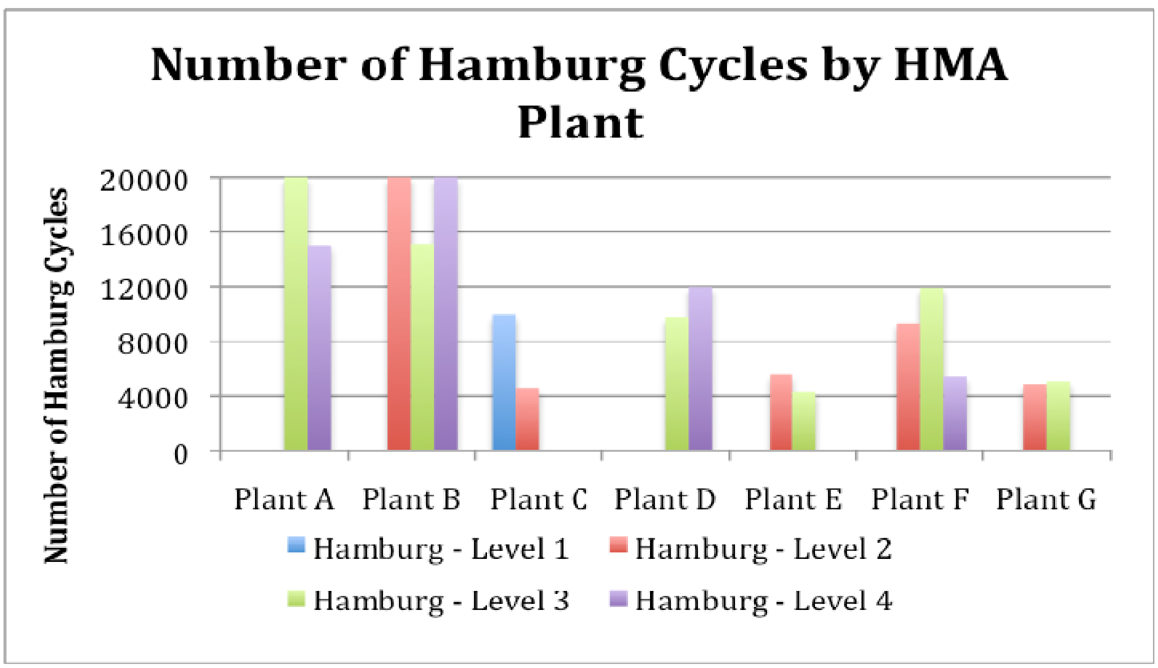

Figure 4 – Hamburg Cycles by Traffic Level and Plant

Figure 5 shows the overall rut depth for each of the mixes tested in the Hamburg test. The results of this test are quite interesting as the Level 2 material, exhibited the lowest rut depths. This may be indicative of the increased asphalt content reducing the effect of the pore pressure in the specimens. Figure 6 shows the Hamburg rut depths for each traffic level and plant.

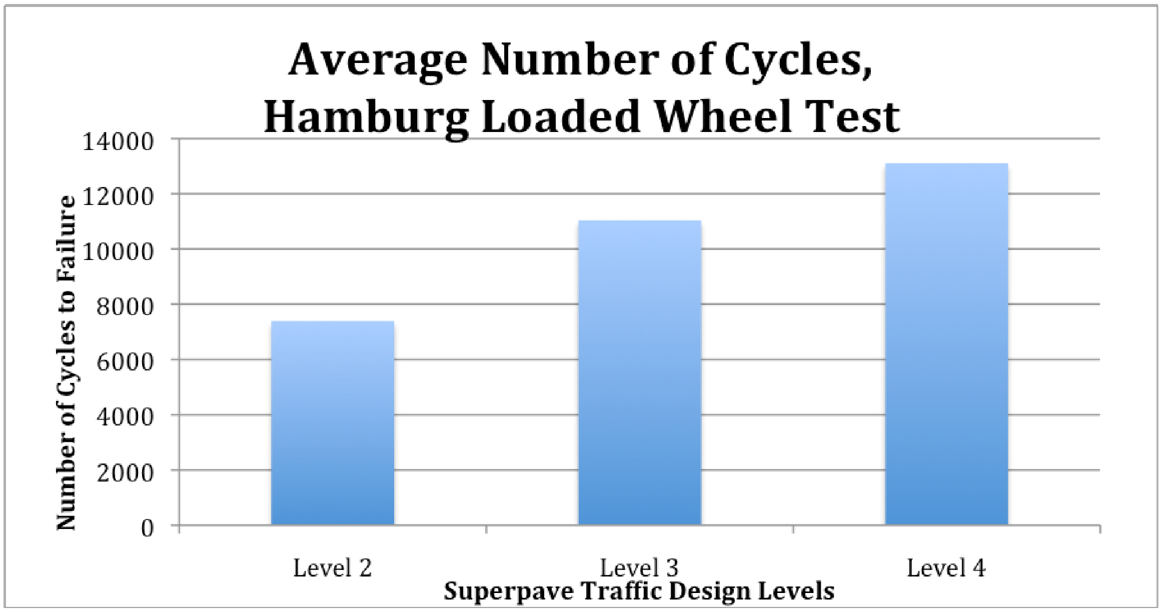

Figure 5 – Number Cycles to Failure. Hamburg Loaded Wheel Tester

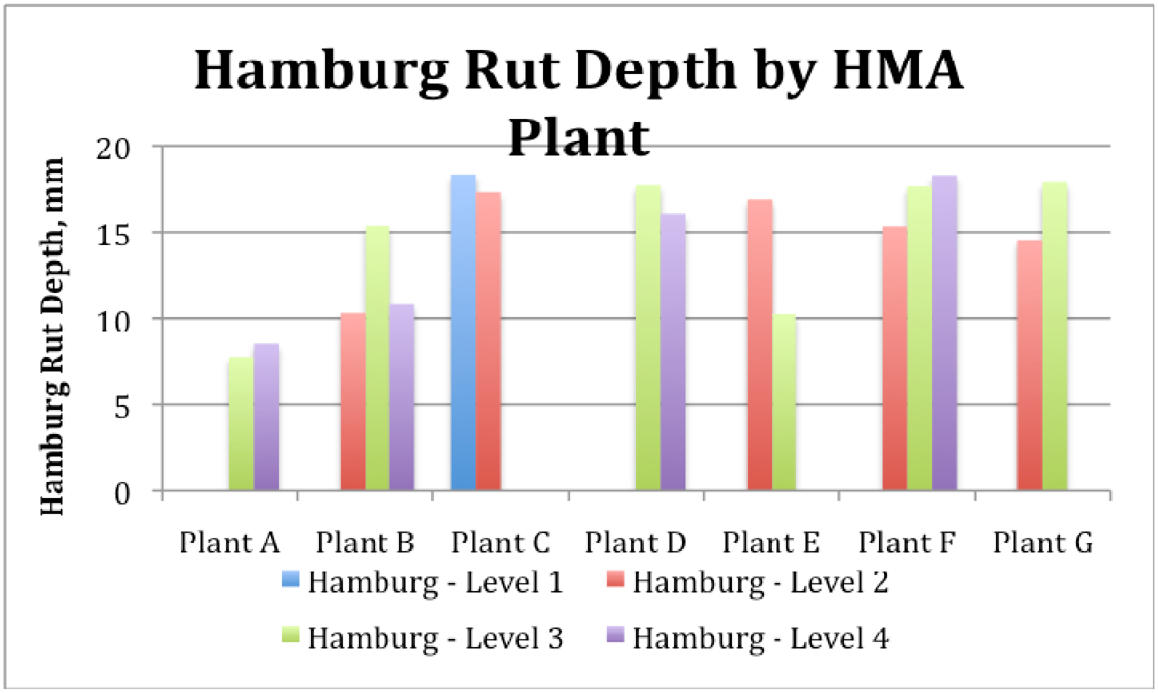

Figure 6 – Hamburg Rut Depth by Traffic Level and Plant

Statistical Analysis of Rut Depth Data

A statistical analysis of rut depth was performed based on Superpave traffic level. The results of an ANOVA analysis indicate there is no statically significant difference between the different mix designs in terms of rut depth. However, testing from multiple plants, multiple mixes and the limited number of samples tested limits our confidence in the significance of the findings.

A box plot was generated to graphically display the variability, mean and median of the three different Superpave levels tested (Figure 7). Superpave traffic level 1 was not included because only one sample was tested at this level. In these box plots, the median is represented by the horizontal line within the box, the mean is represented by a black cross and the upper and lower quartiles are represented by the extent of the boxed region. The whiskers on the box plot extend 1.5 times the inter-quartile range beyond the upper and lower quartiles. This plot confirms that there is no statistically significant differences between the levels since all the boxes overlap in rut depth range. In Figure 7, Traffic Level 4 has the least amount of variability (smallest box) while Levels 2 and 3 have a similar amount of variability in the measured rut depth. Furthermore for traffic level three the mean is larger than the median. This indicates the data for this level are skewed towards a lower APA rut depth with the exception of one or two larger APA rut depth values which cause an increase in the mean but do not impact the median. The confounding impacts of multiple mix producers and multiple mix designs make interpreting the results solely on traffic levels difficult. The source of the variability could be related to type of aggregate used and not be associated with traffic level at all.

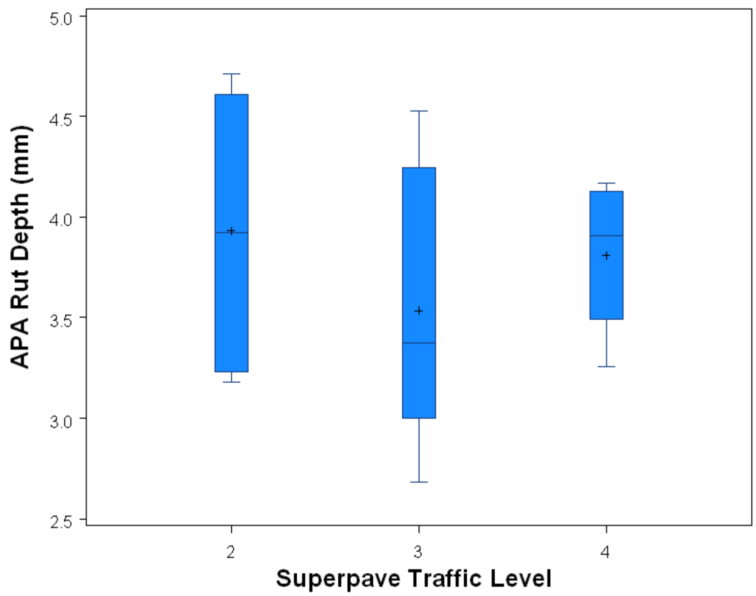

Figure 7 - Box Plot of APA Rut Depth by Traffic Level

Rut data from the Hamburg test was also analyzed with similar results. In the Hamburg test, there was no statistically significant difference between the mixes; however, the box plot indicates as the mix level increases the rut depth decreases slightly (Figure 8).

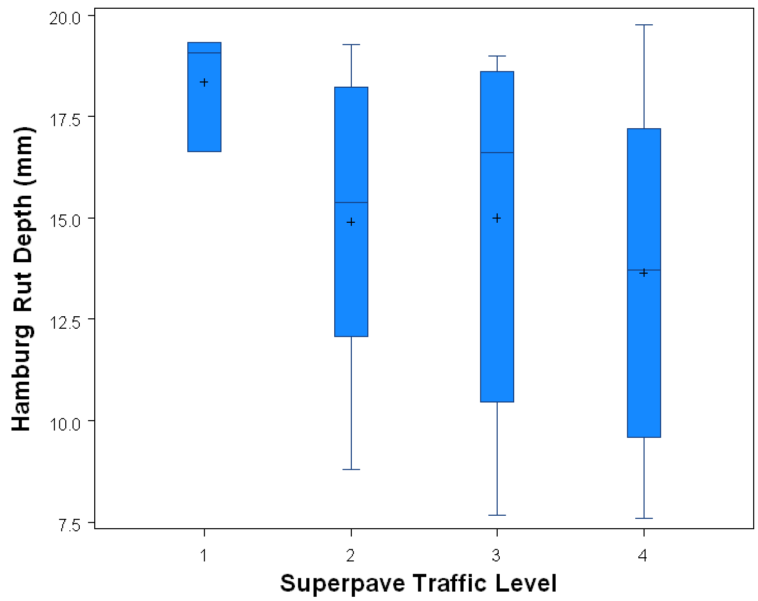

Figure 8 - Box Plot of Hamburg Rut Depth by Traffic Level

Conclusions

While the sample sizes of materials tested may be too small to be able to draw any firm statistical conclusions about the effects of the different traffic levels, it is possible to observe that there does not appear to be any significant differences between the performance of the different levels in the APA and Hamburg tests. There are too many variables to consider when examining the different mixes with this small sample size. The number of samples required to capture the all of the variables is quite large and it would not be practical to conduct all of the testing.

The average rut depths observed with the APA test for all of the materials were not very large. This is a positive sign that the Superpave mixes used here in Connecticut are not prone to rutting and other forms of plastic deformation. The fact that there was not a significant difference in rut depth between Levels 2 and 4 shows that the Superpave mixes in Connecticut are quite capable of withstanding loading from traffic.

The results from the Hamburg test indicate that there are not significant differences in the Superpave mixes used in Connecticut. The analysis of this data is somewhat more complicated as there are two factors that affect the outcome of the test results, the number of cycles and the rut depth as well as the aggregate and asphalt binder interaction. Using the average rut depths for each level of mix does not capture what is occurring within each HMA production facility as there are several large test result differences that are influencing the overall average values. Therefore, it may be more telling to compare the results for each of the plants individually. When looking at the data from individual plants, there are many instances where the lower level mixes required almost the same number of cycles to fail or actually more cycles to fail as compared to the next highest level (Figure 4). A similar comparison can be made between Hamburg rut depths by looking at the results for each HMA plant. There are many instances when the lower level mixes had comparable rut depths as compared to the higher level mixes. Examining the data for each HMA plant for the Hamburg test results does not show any substantial differences between most mixes.

As most of the Superpave mixes for each HMA production facility utilize the same aggregates with little or no difference in the blending of them in the production of Superpave, it is not surprising that there is little difference between the performance of the Superpave mixes in the Hamburg and APA tests.

Recommendations

Based upon the results of the research and testing conducted as part of this project, the research team makes the following recommendations.

- The use of Superpave traffic design Level 4 be eliminated for the purposes of the number of gyrations in the Superpave gyratory compactor as these mixes typically have the least amount of asphalt binder in them and yet the testing conducted did not show any significant difference in its ability to resist permanent deformation. This increase in asphalt binder content should improve the ability of the HMA to resist environmental damage.

- For areas that have a particular history of permanent deformation problems, it is recommended to use Level 3 mixes with an elastomeric polymer modified asphalt to mitigate those issues.

- When specifying Superpave mixes for roadways that that are borderline between two levels, it is recommended that the lower Superpave traffic design level be specified.

- It also recommended that the aggregate requirements remain unchanged for the various traffic design levels. To avoid confusion, there may need to be a designation of “aggregate level” and “gyratory level”. This does not appear to present problems for most producers, as they tend to use the same aggregates to make the various levels of Superpave. It would benefit ConnDOT to review this possibility and its potential impacts internally as this seems to be a viable alternative from the perspective of the research team.

- Superpave Traffic Design Level 1 should remain as part of ConnDOT's specifications even though it is rarely used by ConnDOT. Eventually, municipalities should be switching to Superpave and they will need the Level 1 mixes as they are the most resistant to environmental damage which is typically the most damage experienced on low-volume roads.

- Additionally, some investigation should be conducted to understand municipalities' reluctance to switch to Superpave and attempt to address the issues identified. It is the authors' belief that Level 1 Superpave mixes would benefit the municipalities' paving programs.

References

Halladay, M., (1998). "The Strategic Highway Research Program: An Investment That Has Paid Off." *Public Roads*. March/April 1998. Vol. 61. No. 5.

TRB, (2005) "SUPERPAVE: Performance by Design." Final Report of the TRB SUPERPAVE Committee. ISBN 0-309-09414-3.

TRB, (1984). "America's Highways: Accelerating the Search for Innovation." Transportation Research Board. Special Report 202. ISSN: 0360-859X.

American Association of State and Highway and Transportation Officials, "Standard Specifications for Transportation Materials and Methods of Sampling and Testing", 27th edition, 2007.

American Association of State and Highway and Transportation Officials, "2007 Provisional Standards," 2007.

.

Appendix A - Four Design Level Job Mix Formulas at Various Plants

Plant A

JMF

	level 3	level 4
3/4"	100	100
1/2"	97	97
3/8"	77	77
#4	56	45
#8	44	32
#16	29	22
#30	19	15
#50	12	10
#100	7	6
#200	3	3

JMF Pb	5.20	4.50

Note: DOT requires a minimum Pb of 4.7%, we adjusted our mixes to meet the requirement.

Gmm (CAP lab)	2.668	2.669

Plant B

JMF

	level 2	level 3	level 4
3/4"	100	100	100
1/2"	97	95	90
3/8"	80	86	83
#4	57	65	62
#8	39	45	41
#16	28	30	28
#30	18	22	18
#50	14	14	12
#100	6	9	6
#200	4	4	4

JMF Pb	5.10	4.90	4.90

Gmm (CAP lab)	2.628	2.628	2.656

Plant C

JMF	level 1	level 2
1"	100	100
3/4"	98	100
1/2"	92	94
3/8"	78	76
#4	58	61
#8	47	53
#16	37	43
#30	26	26
#50	15	13
#100	8	5
#200	3	3

JMF Pb	5.20	5.2

Gmm (CAP lab)	2.514	2.505

Plant D

JMF

	level 3	level 4
3/4"	100	100
1/2"	95	95
3/8"	79	80
#4	48	49
#8	35	38
#16	30	29
#30	25	24
#50	13	13
#100	5	6
#200	3	3
Pb	5.00	4.90
Gmm (CAP lab)	2.661	2.655

Plant E

JMF

	level 2	level 3
3/4"	100	100
1/2"	95	95
3/8"	78	75
#4	56	48
#8	42	35
#16	33	27
#30	26	20
#50	16	13
#100	8	6
#200	4	3

Pb	5.20	4.60

Note: DOT requires a minimum Pb of 4.8% on a level 3 mix we adjusted our samples to meet the requirement.

Gmm (CAP lab)	2.560	2.597

Plant F

JMF

	level 2	level 3	level 4
3/4"	100	100	100
1/2"	95	95	95
3/8"	75	75	77
#4	53	51	51
#8	42	40	40
#16	32	32	32
#30	26	26	26
#50	19	17	17
#100	8	8	8
#200	3	3	3

Pb	5.30	5.10	5.10

Gmm (CAP lab)	2.596	2.601	

Plant G

JMF

	level 2	level 3
3/4"	100	100
1/2"	94	94
3/8"	85	85
#4	70	70
#8	52	52
#16	43	40
#30	32	31
#50	20	18
#100	12	10
#200	6	5

Pb	5.70	5.40

Gmm (CAP lab)	2.604	2.610