CTDOT Specification Requirements for Minimum Asphalt Requirements

FINAL REPORT

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Connecticut Advanced Pavement Laboratory
Connecticut Transportation Institute
School of Engineering
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Acknowledgments

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Standard Conversions

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		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
		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
		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
		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 (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		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

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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CTDOT minimum asphalt requirements have resulted in roadway mixes being produced with finer aggregate gradations in recent years than they have in the past. This research was conducted to investigate the possibility of lowering the minimum asphalt content requirements in an effort to drive the mix gradations coarser without compromising the performance quality of the mix. CTDOT Superpave mixes were collected from multiple HMA production facilities during production. Constituent aggregates for each of the mixes were also collected. Rutting susceptibility testing, moisture susceptibility testing along with fatigue and reflective cracking damage susceptibility testing were performed on the collected mixes. The aggregates were then recombined at lowered asphalt contents to produce specimens that were subjected to the same performance tests as the original mix for comparison. Performance test results indicate that the current CTDOT minimum asphalt content requirements are optimized and there are no recommendations to change the specifications as a result of this research.</td></tr>
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Introduction and Background Summary

The transition to the Superpave [1] mix design procedure was a substantial change from the previous Hot Mix Asphalt (HMA) design method used by the Connecticut Department of Transportation (CTDOT). CTDOT had used the Marshall Mix design method for several decades, and the various CTDOT mixes were differentiated only by the size of the coarse aggregate used in the mixture. One of the most significant changes with Superpave HMA mixes is that they are differentiated not only by the coarse aggregate size, but also by four traffic levels. Having four traffic levels for each coarse aggregate sized mix is beneficial for ensuring the longevity of the pavement, as HMA pavements typically develop two significant types of damage. Environmental damage occurs to all pavements as a direct result of thermal cycling, oxidation of the asphalt binder and from contact with water. Damage from loading, particularly from heavy trucks, increases with the volume of traffic. The premise of Superpave is that the most significant damage that occurs on low volume roads is typically environmental. For high-volume roadways, however, traffic loading is typically the cause of the majority of the damage.

Environmental damage to HMA pavements can be purposely delayed by increasing the asphalt binder content. Additional binder increases the film thicknesses covering all of the aggregates, thereby slowing down the rate of oxidation. This helps the pavement maintain its elasticity for a longer period of time. Unfortunately, increasing the asphalt binder content in HMA pavements increases the chances that the pavement will suffer from permanent deformation as the weight of traffic loading increases. Consequently, the lowest traffic level for Superpave mixes has the highest asphalt binder content, and the highest traffic level has the lowest asphalt binder content.

Even with different traffic levels within the Superpave system, anecdotal observations were that the Superpave mixes tended to contain too little asphalt and this, in turn, was leading to premature distresses within the pavement. To combat that issue, many states implemented a minimum asphalt content requirement for their Superpave mixes based upon the coarse aggregate size in the mixture. In addition, other states reduced the anticipated traffic loadings which, through mix design procedures, increased the amount of asphalt binder in the mixtures.

In recent years, CTDOT implemented a minimum asphalt content and eliminated the highest Superpave traffic level, in order to increase the asphalt binder in the mixtures. The minimum asphalt binder content requirement could produce unexpected consequences, where if the minimum asphalt content is too high, the gradation of the HMA is impacted. To meet the volumetric requirements, the HMA producers are using a finer aggregate gradation than they used prior to the minimum asphalt requirement to increase the overall surface area of the aggregates in the mixture. This achieves the minimum asphalt content while still meeting the volumetric requirements. A potential benefit of producing coarser mixes, as a result of lowering the minimum asphalt content, could be an increase in surface texture. This, in turn, could help to increase friction between vehicle tires and the roadway surface.

Problem Statement

The current Superpave minimum asphalt content requirements for CTDOT may be too high, and as a result could be forcing the aggregate gradations to be finer than what is desired for an optimal pavement surface texture. It may be possible to reduce the minimum asphalt content requirements to enhance the pavement surface texture without sacrificing pavement durability. A reduction in the minimum asphalt binder content will also reduce the chances of having asphalt binder bleed to the pavement surface and create a safety concern.

Objectives

The objective of this research is to determine if a reduction of the minimum asphalt content specification requirements in CTDOT Superpave mixes could be achieved without affecting long-term pavement durability and performance. This could result in these mixes being produced with coarser gradations, which has the potential for increased roadway surface friction.

Work Summary

The first undertaking of this research was to review nearby state specifications to see if any insight could be gained from what the surrounding state agency requirements are compared with CTDOT requirements.

The next task was to collect common CTDOT mixes from multiple producers for testing along with samples of all of the constituent aggregates used in each mix. This included both an S0.5 mix (CTDOT nominal 0.5-inch mix) and an S1 mix (CTDOT nominal 1.0-inch mix) from each of four different producers. These mixes were sampled from haul units at the sampling stand at each production facility. The aggregates were sampled from stockpiles at each of the respective facilities on the same day/night the mix was collected.

The mixes were then subjected to various performance tests in order to establish a basis for comparison. These tests include: APA rutting susceptibility testing [2]; hamburg wheel-track testing (AASHTO T324) [3]; tensile strength ratio (AASHTO T283) [4]; and, Overlay testing (Tex-248-F) [5]. Images of these tests are shown in Figures 1 through 4.

The mixes were then recreated in the laboratory at lowered asphalt contents utilizing the aggregates that were collected at the production facilities. The asphalt contents were lowered by 0.1 – 0.4 percent depending on what could be tolerated while still meeting volumetric requirements.

The laboratory mixes with the lowered asphalt contents were then subjected to the same performance tests as the original mixes, for comparison purposes. The intent was to determine if the mix performance would be compromised at the lowered asphalt contents.

Review of Literature and Specifications

The following information was collected to gain perspective as to what some of the surrounding State agency requirements are with respect to minimum asphalt percentages in relation to the CTDOT requirements. This information is relevant since most of the aggregates in the states in this region have low absorption rates similar to Connecticut, which would have a minimal effect on any required liquid asphalt content.

Connecticut Department of Transportation

The CTDOT requirements for the minimum asphalt content of Superpave mixes were taken directly from the Standard Specifications [6] and are shown in Table 1. It should be noted that the numbers in the mix type column correspond to the nominal size of the mix.

Table 1: CTDOT Minimum Asphalt Requirements

Superpave Minimum Binder Content by Mix Type and Level

Mix Type	Level	Binder Content Minimum
S0.25	1*	5.6
S0.25	2	5.5
S0.25	3	5.4
S0.375	1*	5.6
S0.375	2	5.5
S0.375	3	5.4
S0.5	1*	5.0
S0.5	2	4.9
S0.5	3	4.8
S1	1*	4.6
S1	2	4.5
S1	3	4.4

***NOTE: Level 1 for use by Towns and Municipalities ONLY.**

For reference, the number after the "S" in the Mix Type column in Table 1 refers to the nominal size of the mix in inches. S0.25 is the nominal quarter-inch mix. S0.375 is the nominal 3/8"-mix equal to 9.5 mm. S0.5 is the nominal half-inch mix equal to 12.5 mm. S1 is the nominal one-inch mix equal to 25 mm.

Maine Department of Transportation

The Maine Department of Transportation (MaineDOT) [7] did not require any certain quantity of liquid asphalt per mix at the time this research was conducted. The specification requires the mix design to meet volumetric requirements as well as pertinent information about the liquid asphalt as stated:

“The JMF shall state the original source, gradation, and percentage to be used of each portion of the aggregate including RAP when utilized, and mineral filler if required. It shall also state the proposed PGAB content, the name and location of the refiner, the supplier, the source of PGAB submitted for approval, the type of PGAB modification if applicable, and the location of the terminal, if applicable.”

Vermont Agency of Transportation

The Vermont Agency of Transportation (VAOT) [8] did not require any certain quantity of liquid asphalt per mix at the time this research was conducted. The specification does state that the liquid asphalt percentage must meet the job mix formula, and also states how that percentage will be determined for both Superpave and Marshall mixes:

“The quantity of PG asphalt binder introduced into the mixer shall be that quantity specified as a percentage in the accepted job-mix formula and, for batch plants, will be accepted on the basis of the mass (weight) on the printed weight slip. For the use of drum-mix plants, the quantity of PG asphalt binder shall be specified as a percentage in the accepted job-mix formula, and will be accepted on the basis of the percentage printed on the demand ticket from the approved automatic digital recording device in the plant.”

Massachusetts Department of Transportation

The Massachusetts Department of Transportation (MassDOT) [9] maintains requirements regarding minimum liquid binder content of HMA mixes. First, there is a target range for standard top courses between 5.6% and 7.0% by weight of the mixture. There is also a requirement that states:

"Unless authorized by the Engineer, no Job-Mix Formula will be approved which specifies:

- *Less than 6% binder for HMA Surface Course – Standard Top*
- *Less than 5.5% binder for HMA Surface Course – Dense Binder and HMA Surface Course – Modified Top for Mixes Containing RAP."*

Following these requirements for binder contents, are the tolerances for the target JMF binder content which is ± 0.4%.

New Hampshire Department of Transportation

The New Hampshire Department of Transportation (NHDOT) [10] has a requirement for the minimum amount of liquid asphalt binder to be added to HMA mixtures. The requirement is based on both traffic level and nominal mix size. The requirement is shown in Table 2.

Table 2: NHDOT Minimum Asphalt Requirement

Minimum Binder Content

50 Gyration		75 Gyration
	3/8"	6.0%
5.8%	1/2"	5.5%
4.9%	3/4"	4.6%
4.6%	1"	4.3%

The specification further states that these requirements are for typical/common aggregate specific gravities of 2.65 – 2.70, and that, as specific gravity may vary from this range, the minimum liquid content may be adjusted at the discretion of the Engineer.

New York State Department of Transportation

The New York State Department of Transportation (NYSDOT) [11] specifies minimum asphalt binder contents dependent upon the nominal size of the mixture:

"… select the design PG binder content that results in a compacted density of 96.5% of Gmm at the design number of gyrations (N design). Under no circumstances, shall the PG binder content in the HMA mixture be less than 5.8%for a 9.5 design, 5.2% for a 12.5, 4.5% for a 19.0 design, 4.2% for a 25.0 design, or, 3.7% for a 37.5 design. All volumetric and mechanical properties are checked at this PG binder content to ensure that all requirements are met.

Summary of Reviewed Specifications

Of the agencies that were reviewed that had minimum binder requirements on 12.5-mm (S0.5) mixes, CTDOT had the lowest requirement, regardless of traffic level. For specified 25-mm (S1) mixes, CTDOT was within 0.1% - 0.2% of the minimums set forth in the other reviewed agency specifications.

Collection of Mixes and Lab Mixing at Lowered Asphalt Contents

The research team collected mixes from four different producers. Both S0.5 and S1 Superpave mixes were collected from each of the four producers. The mixes were collected at sampling stands from haul units during production. All of the plant produced mixes that were collected met CTDOT volumetric requirements. The constituent aggregates from each of the mixes were sampled, as well.

The mixes that were collected were simply reheated and compacted at the required dimensions and air void contents to comply with specimen parameters for each of the performance tests.

The aggregates that were collected at each site were recombined with virgin asphalt (PG 64-22) at the lowered asphalt contents. Efforts were made to keep the gradations as close to the gradations of the original mixes as possible. Some slight adjustments needed to be made in order to lower the asphalt content while still meeting volumetric requirements. The mixes were then oven-aged and used to create test specimens that met Superpave volumetric requirements. These test specimens were used for performance testing to provide comparisons with the original mix from each of the four producers.

Performance Testing of Collected Mixes and Laboratory Mixes

The tests used for performance comparisons were: APA rut testing; Hamburg Wheel-Track testing; Tensile Strength Ratio (TSR); and, Overlay testing. These tests were chosen in an effort to cover a variety of different performance measures that mixes are expected to exhibit over the lifespan of the pavement. APA and Hamburg testing (Figures 1 and 2) both provide indications of the mixture's susceptibility to rutting. The APA test (Figure 1) consists of repeated 100-pound wheel loading over a pressurized (100 psi) pneumatic tube that is centered over the test specimens at the high performance grade temperature of the asphalt binder in the mix. These particular mixes were run at a temperature of 64 ºC. The test concludes after the completion of 8,000 cycles at which point the rut depth is reported by the machine software. Rutting is reported in millimeters. When comparing the test results of the original mixes to the lab mixes, the rut depth with the lowest value is the most desirable.

All of the original plant produced mixes and the lower Pb (percent binder or asphalt content) laboratory produced mixes were subjected to this suite of performance testing.

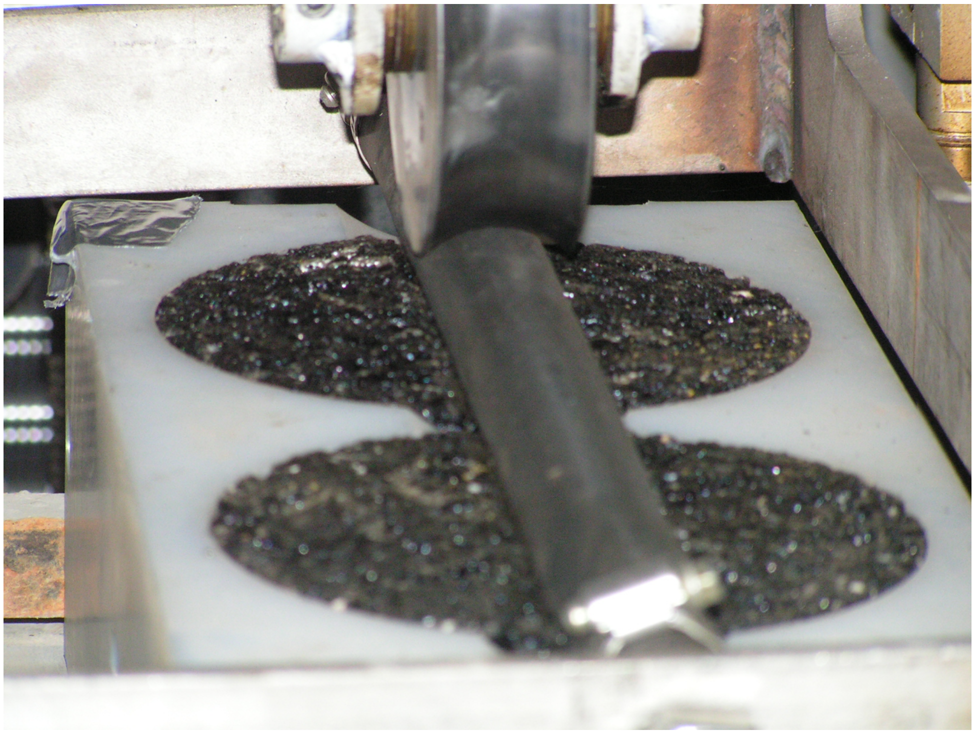

Figure 1: APA Testing

The Hamburg Wheel--Track test (Figure 2) consists of repeated 158-pound wheel loading directly on the test specimens at 45º C. This test is conducted under water.

For analyzing and comparing rutting susceptibility between mixes, the rut depth with the lowest value is the most desirable.

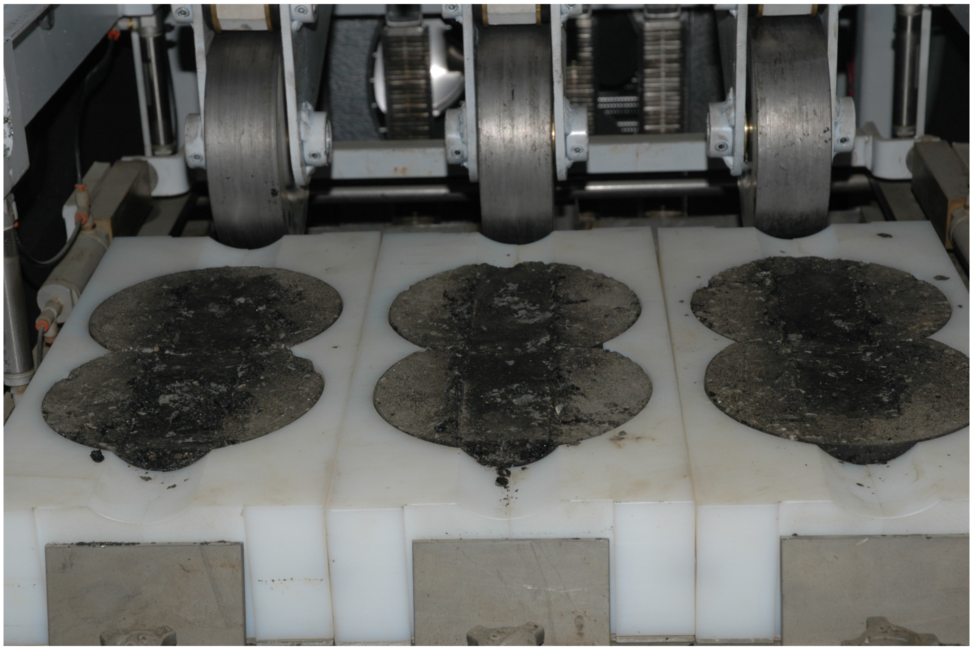

Figure 2: Hamburg Wheel-Track Testing

The Hamburg test can be used as an indicator of the mixture's susceptibility to moisture induced damage. The Hamburg wheel-track test is conducted under water. If, or when, stripping occurs, the rate of rutting increases, and a plot of the results will then show a stripping inflection point (SIP), where the onset of stripping occurred. When an SIP is observed, it is an indication that the mixture is susceptible to moisture induced damage.

Tensile strength ratio testing (Figure 3) is used to determine the change in tensile strength of the mix after it has been partially saturated and subjected to a freeze-thaw cycle (conditioned). A reduction in tensile strength can be an indicator that water is breaking the bond between the asphalt binder and the aggregate. The TSR is the ratio of the tensile strength of the conditioned mix to the tensile strength of unconditioned mix. When comparing the results of two different mixes, a higher TSR value is more desirable.

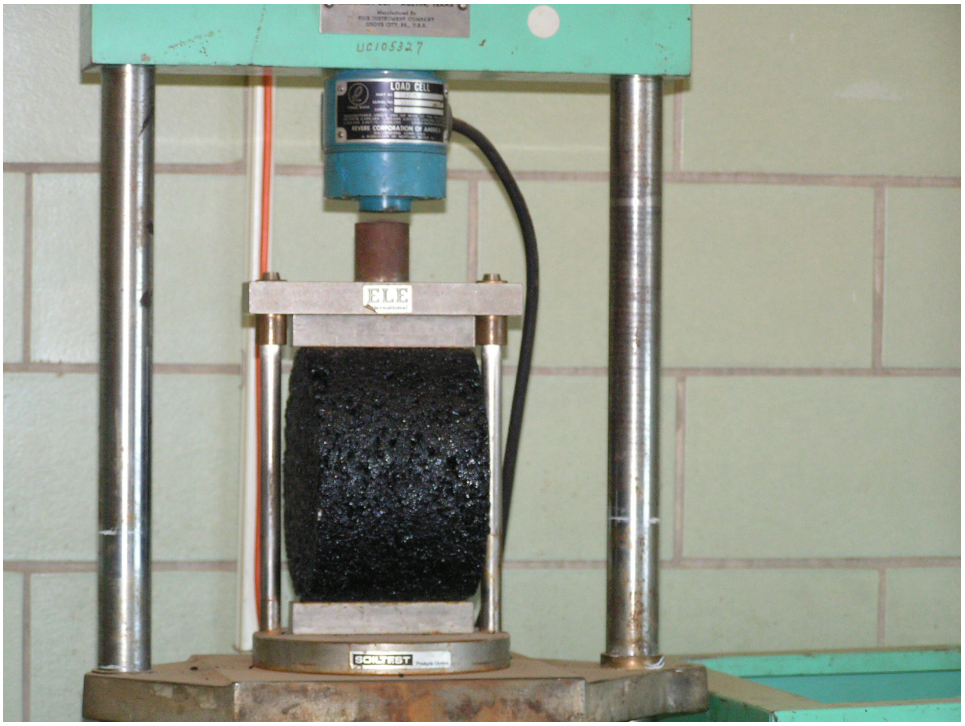

Figure 3: TSR Testing

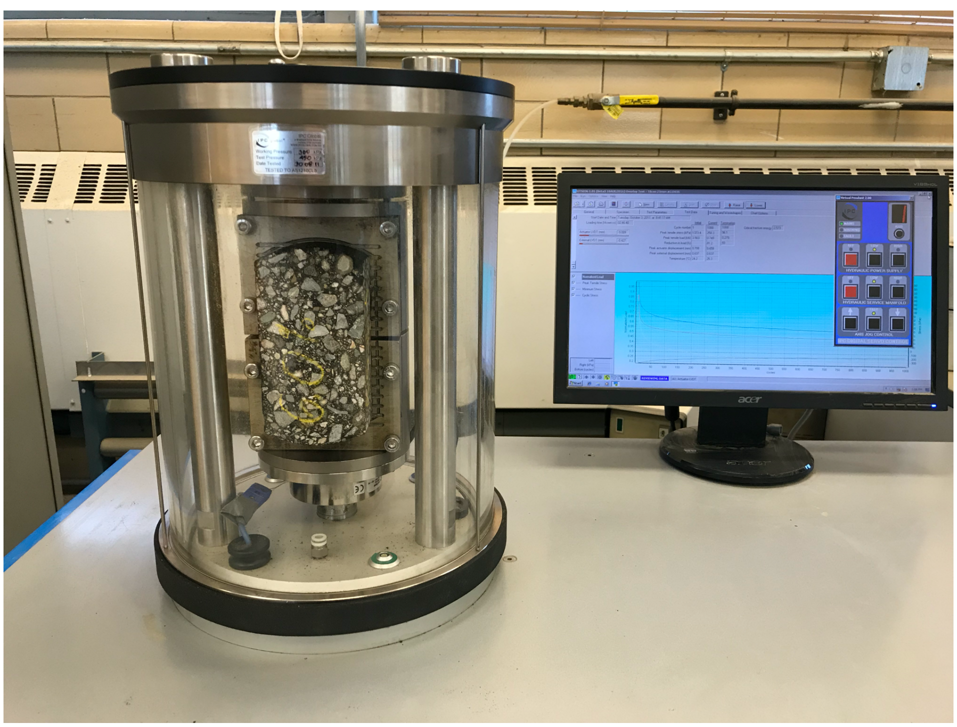

Figure 4: Overlay Testing

Overlay testing (Figure 4) is used to indicate the mixture's susceptibility to both reflective cracking and fatigue damage. The Overlay test begins by applying the tensile load that is necessary to elongate the test specimen 0.635 mm on the first cycle. This initial tensile load is the parameter against which subsequent loads are compared as the specimen loses its tensile strength. The test measures the reduction in the load that is necessary to repeat this elongation for up to 1,000 cycles. If a 93.0 % reduction in load is measured at any time during the test, the loading terminates and the test is concluded. For comparing the plant versus lab mixes, the first point of interest looks at the ability of each mix to withstand all 1,000 cycles, and then, a comparison of the total reduction of the required tensile load. The higher the reduction in load, the more susceptible to damage via fatigue and reflective cracking the mix is. This test is conducted at 25 ºC.

Asphalt Pavement Analyzer Rut Testing Results S0.5 Mixes

The APA rut depth testing was conducted at the binder high performance grade of 64 ºC. The APA rut depths measured for the S0.5 mixes showed mixed results. Two of the lowered asphalt mixes had lower rut depths than the plant mixes. One plant mix had a lower rut depth than the lab mix, and one set of results were identical. All specimens endured the full 8,000 cycle test. Results of the APA testing on S0.5 mixes are shown in Table 3.

Table 3: S0.5 APA Rut Testing Results

Producer		Pb	APA rut depth (mm)	Δ (mm) at Lowered Asphalt Content
A	Plant Mix	5.1	3.25	**0.54**
	Lab Mix	4.7	3.79	
B	Plant Mix	4.9	5.57	**-1.45**
	Lab Mix	4.8	4.12	
C	Plant Mix	5.0	5.93	**0**
	Lab Mix	4.8	5.93	
D	Plant Mix	5.1	8.47	**-5.49**
	Lab Mix	4.8	2.98	

Hamburg Wheel-Track Testing Results S0.5 Mixes

All of the Hamburg testing was conducted at 45 ºC. All of the S0.5 mixes that were tested with lower asphalt contents had increased rut depths compared to the original plant mix. This is opposite of what was expected. This may be due (at least in part) to the lab-produced mix not quite matching the plant-produced conditions. The increased rut depths are none-the-less an indication that the mixes could be more prone to rutting at lowered asphalt contents. The rut depths of all of the S0.5 mixes, along with the change in rut depth, are shown in Table 4. There were no observed stripping inflection points on any of the mixes. This is an indication that stripping due to moisture induced damage is not a concern for these mixes. It should be noted that the test wheel stopped after 19,880 passes on one of the lab mix specimens for Producer B. This occurs when one of the rut depths reaches a maximum set value. All other specimens endured the full 20,000 cycle test.

Table 4: S0.5 Hamburg Wheel-Track Results

Producer		Pb	Rut Depth (mm)	Δ (mm) at Lowered Asphalt Content	SIP
A	Plant Mix	5.1	4.15	**2.61**	N/A
	Lab Mix	4.7	6.76		
B	Plant Mix	4.9	7.98	**0.57**	N/A
	Lab Mix	4.8	8.55		
C	Plant Mix	5.0	11.76	**2.26**	N/A
	Lab Mix	4.8	14.02		
D	Plant Mix	5.1	7.82	**4.41**	N/A
	Lab Mix	4.8	12.23		

Tensile Strength Testing (TSR) Results S0.5 Mixes

Results of TSR testing show that three of the four mixes with lowered asphalt contents had lower tensile strength ratios than their plant mix counterparts, while one mix showed an increase in tensile strength. These results are shown in Table 5.

Table 5: S0.5 TSR Testing Results

Producer		Pb	TSR %	Δ (%)at Lowered Asphalt Content
A	Plant Mix	5.1	97.0	**-10.0**
	Lab Mix	4.7	87.0	
B	Plant Mix	4.9	69.5	**6.3**
	Lab Mix	4.8	75.8	
C	Plant Mix	5.0	71.0	**-1.7**
	Lab Mix	4.8	69.3	
D	Plant Mix	5.1	92.0	**-15.9**
	Lab Mix	4.8	76.1	

Overlay Testing S0.5 Mixes

The Overlay test begins by applying the tensile load that is necessary to elongate the test specimen 0.635 mm on the first cycle. This initial tensile load is the parameter against which subsequent loads are compared as the specimen loses its tensile strength. The test measures the reduction in the load that is necessary to repeat this elongation for up to 1,000 cycles. If a 93.0 % reduction in load is measured at any time during the test, the loading terminates and the test is concluded. For comparing the plant versus lab mixes, interest lies with the ability of each mix to withstand all 1,000 cycles and then a comparison of the total reduction of the required tensile load. The higher the reduction in load, the less damage-resistant the mix is. The crack resistance index (in accordance with the Tex-248-F Specification) is another performance indicator that characterizes cracking resistance of asphalt mixtures. It is done by fitting the power equation of the tensile load versus cycles to failure. Unfortunately, as of this time, the software that runs the overlay test in the Asphalt Mixture Performance Tester (AMPT) is not capable of power fitting equations, so the load reduction percentages were used as the comparative measure.

Three specimens per mix were tested, and the load reductions were then averaged for each mix. Table 6 shows the results of this testing for the S0.5 mixes. All of the plant mixes outperformed the lowered asphalt mixes. However, mixes A, C and D were all close to the plant mix reduction, while the lab mix for producer B sustained a considerably higher reduction in tensile loading.

Table 6: S0.5 Overlay Testing Results

Producer		Pb	% Reduction	Δ (%) at Lowered Asphalt Content
A	Plant Mix	5.1	81.5	**0.4**
	Lab Mix	4.7	81.9	
B*	Plant Mix	5.0	68.6	**20.4**
	Lab Mix	4.8	89	
C	Plant Mix	4.9	80.4	**1.8**
	Lab Mix	4.8	82.2	
D	Plant Mix	5.1	76.0	**1.2**
	Lab Mix	4.8	77.2	

***2 of the 3 Producer B Laboratory Mix specimens did not tolerate all 1,000 cycles.**

Conclusions from Performance Testing of S0.5 Mixes

Two of the APA rut testing results and one TSR result at lowered asphalt content showed an increased level of performance. All of the other comparative tests resulted in either a decreased level of performance or no change in performance. Given the compiled results, there appears to be no reason that lowering the CTDOT minimum asphalt content on standard S0.5 mixes would be advantageous to the performance of the pavements. In other words, a reduction in minimum asphalt content is not shown to be justified for S0.5 mixes.

Asphalt Pavement Analyzer Rut Testing Results S1 Mixes

With the exception of one of the mix comparisons (Producer B), the APA rut testing results from the S1 mixes showed that the mixes with lowered asphalt contents had lower rut depths than the original plant mixes. The APA results are shown in Table 7.

Table 7: S1 APA Rut Testing Results

Producer		Pb	APA rut depth (mm)	Δ (mm) at Lowered Asphalt Content
A	Plant Mix	4.7	4.05	**-0.26**
	Lab Mix	4.4	3.79	
B	Plant Mix	4.5	2.89	**0.96**
	Lab Mix	4.3	3.85	
C	Plant Mix	4.7	5.87	**-1.76**
	Lab Mix	4.5	4.11	
D	Plant Mix	4.7	6.44	**-2.7**
	Lab Mix	4.3	3.74	

Hamburg Wheel-Track Testing Results S1 Mixes

Hamburg testing of the S1 mixes showed very different results than the S0.5 mixes. All of the mixes tested at lowered asphalt contents had lower rut depths than the original plant mixes. There were no stripping inflection points observed for any of the specimens. All of the specimens endured the 20,000 cycle test. Results are shown in Table 8.

Table 8: S1 Hamburg Wheel-Track Results

Producer		Pb	Rut Depth (mm)	Δ (mm) at Lowered Asphalt Content	SIP
A	Plant Mix	4.7	7.65	**-0.84**	N/A
	Lab Mix	4.4	6.81		
B	Plant Mix	4.5	7.61	**-0.41**	N/A
	Lab Mix	4.3	7.20		
C	Plant Mix	4.7	8.64	**-1.37**	N/A
	Lab Mix	4.5	7.27		
D	Plant Mix	4.7	9.21	**-0.95**	N/A
	Lab Mix	4.3	8.26		

Tensile Strength Testing (TSR) Results S1 Mixes

Results of TSR testing show that two of the four mixes with lowered asphalt contents had lower tensile strength ratios than their plant mix counterparts. While two of the lab mixes (Producers B and C) had higher tensile strength ratios than the original plant mixes, it should be noted that the original mixes still passed the CTDOT threshold requirement of 80.0 %. The two lab mixes that had lower tensile strength ratios than the original mixes did not pass the CTDOT 80.0 % requirement. These results are shown in Table 9.

Table 9: S1 TSR Testing Results

Producer		Pb	TSR, %	Δ (%) at Lowered Asphalt Content
A	Plant Mix	4.7	80.5	**-4.3**
	Lab Mix	4.4	76.2	
B	Plant Mix	4.5	81.8	**1.2**
	Lab Mix	4.3	83	
C	Plant Mix	4.7	83.3	**-5.4**
	Lab Mix	4.5	77.9	
D	Plant Mix	4.7	80.2	**0.4**
	Lab Mix	4.3	80.6	

Overlay Testing S1 Mixes

Two of the mixes with lowered asphalt contents had increased load reductions, compared with the original mixes, while two registered higher. Increased reductions in the tensile load are an indication that the mix is more susceptible to fatigue damage and reflective cracking. The Overlay testing results for all producers are shown in Table 10.

Table 10: S1 Overlay Testing Results

Producer		Pb	% Reduction	Δ (%) at Lowered Asphalt Content
A	Plant Mix	4.7	77.6	**-0.7**
	Lab Mix	4.4	76.9	
B	Plant Mix	4.5	78.0	**5.5**
	Lab Mix	4.3	83.5	
C	Plant Mix	4.7	79.1	**-6.8**
	Lab Mix	4.5	72.3	
D*	Plant Mix	4.7	82.0	**6.1**
	Lab Mix	4.3	88.1	

***One of the Producer D Laboratory Mix specimens did not tolerate all 1,000 cycles.**

Conclusions from Performance Testing of S1 Mixes

With the exception of the Hamburg and APA rut testing results, the performance of the S1 mixes with lowered asphalt contents versus the original mixes were varied. Both the TSR and Overlay testing results showed that performance at the lowered asphalt contents could possibly be compromised. This could be an indication that fatigue, reflective cracking and moisture susceptibility of the S1 mixes in the field may not yield desirable results. Results show that rutting is the one performance variable that may remain stable if the minimum asphalt content were lowered for the S1 mixes. While this is an encouraging result, other performance testing would need to trend in the same direction before it could be stated, with confidence, that the lower asphalt content would not affect the overall performance of the mix.

Discussion and Recommendations

The CTDOT minimum asphalt standard [6] for S0.5 mixes is already lower than any of the reviewed nearby state agency standards. The CTDOT minimum asphalt requirement for S1 mixes [6] is within 0.1 – 0.2 % of the reviewed agency standards. These findings alone suggest that the CTDOT minimum asphalt requirements may be at optimal levels.

The performance testing that took place during this research shows that lowering the minimum asphalt content on CTDOT S0.5 mixes or S1 mixes would not likely benefit the performance of these mixes. There was even some evidence that the performance could be diminished using a lower minimum asphalt content, for the mixes collected during this study. While a much larger dataset and the incorporation of parametric statistics to verify this outcome would be ideal, the data collected did not support lowering the minimum asphalt content standard for either CTDOT pavement mix.

In addition to the results of this research, is the very reasonable possibility that a reduction in binder could potentially increase the necessary compactive effort in the field. A higher level of necessary compactive effort in the field could yield overall lower field density and, thereby, a decrease in durability and performance.

The Federal Highway Administration and the Asphalt Institute hosted a workshop in CT in 2017. The workshop was focused on pavement durability and performance. One of the primary topics was the need for more asphalt binder in HMA mixes to increase durability and longevity. It was discussed that more asphalt binder in the mix has been shown to increase compaction levels. Since undercompaction leads to premature failure and a decreased service life, it makes sense that reducing the minimum required binder content in CTDOT mixes would not be beneficial. The results of this research align with the emphasis of the workshop.

It is recommended that CTDOT continue to require the minimum asphalt binder contents set forth in the current standard specifications [6] that are shown in Table 1 of this report.

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