FINAL REPORT ~ FHWA-OK-13-02

QC/QA TESTING DIFFERENCES BETWEEN HOT MIX ASPHALT (HMA) AND WARM MIX ASPHALT (WMA)

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16. ABSTRACT
WMA represents a group of technologies which allow a reduction in temperatures at which asphalt mixtures are produced and placed on the road. ODOT Materials Division has conducted preliminary inquiries into QC/QA testing for WMA. Some respondents indicate that WMA can be tested exactly the same as hot mix asphalt (HMA) with the same results. Other data show that lab-molded and other volumetric properties are significantly different for WMA.
The objectives of this study were to develop testing protocols for WMA additives and foamed WMA for mix design and QC/QA procedures. Cold feed belt samples and plant produced samples of mix were obtained and mixed with WMA additives. Mixtures were tested for lab molded voids, maximum specific gravity, moisture sensitivity and resistance to permanent deformation. The effects of reheating the WMA samples on the above mix properties were also evaluated. Recommendations are made for mix design and QC/QA procedures for WMA technologies.

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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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CHAPTER 1
BACKGROUND

INTRODUCTION

WMA represents a group of technologies which allow a reduction in temperatures at which asphalt mixtures are produced and placed on the road. These technologies tend to reduce the viscosity of the asphalt cement allowing coating at lower temperatures. Reductions of 35 to 100^{o}F have been reported (1). Such drastic temperature reductions have the obvious benefits of cutting fuel consumption and decreasing the production of greenhouse gases. In addition, potential engineering benefits include better compaction on the road, the ability to haul paving mix for longer distances, increased RAP percentages, and the ability to pave at lower temperatures (2).

Advances in WMA processes are progressing rapidly. When originally introduced in the US there were three WMA procedures. There currently are a multitude of procedures/technologies either available or proposed. WMA has advanced from demonstration projects to where many agencies, such as Texas DOT, allow the use of WMA technology.

ODOT Materials Division has conducted preliminary inquiries into QC/QA testing for WMA. Some respondents indicate that WMA can be tested exactly the same as hot mix asphalt (HMA) with the same results. Other data show that lab-molded and other volumetric properties are significantly different for WMA.

Originally, equivalent compaction temperatures and/or compactive efforts, those that produce void results for WMA mixtures similar to conventional Superpave mixtures, were recommended for use with WMA technologies. Currently, the recommended compaction temperature is selected by the contractor or supplier and verified in accordance with draft procedures found in section 8.3 of the proposed Appendix to AASHTO R 35 (3).

WMA was originally classified based on the degree of temperature reduction. A mixture is considered WMA if the temperature at the plant exceeds 212^{o}F and half warm mix if the temperature at the plant is less than 212^{o}F. WMA is also classified by technology; those that use water, those that use organic additives or waxes, and those

that use surfactants (1). A third classification is those that use additives and those that are process driven. Process driven technologies tend to be foaming processes and could include Double Barrel Green plants and related technologies, Low Energy Asphalt and WAM-Foam. Bonaquist (4) reported that for mix design purposes WMA technologies are placed into four categories:

- WMA additives that are added to the asphalt binder,
- WMA additives that are added to the mixture during production,
- Sequential mixing processes, and
- Plant foaming processes.

NCHRP 9-43 (3) on WMA mix design practices was recently completed. When this study began there was a draft mix design method available; however, the procedure did not address mixing and compaction temperatures or QC/QA procedures. The proposed mix design method is presented as an appendix to AASHTO R 35 and contains a commentary (3). NCHRP 9-43 recommends the contractor select his own WMA additive and mixing and compaction temperatures. The proposed mix design procedure contains a method for evaluating mixing and compaction temperature based on coatability using AASHTO T 195 and compaction temperature based on compacting samples at the proposed roadway temperature and 30^{o}C less and evaluating the number of gyrations required to reach 92% Gmm. Data presented indicate compaction temperatures range from 270^{o}F to 220^{o}F (4).

Bonaquist (4) reported that, with the exception of Sasobit, WMA technologies perform poorer than equivalent HMA mixes in rutting tests and that WMA and equivalent HMA mixes can have similar TSRs from AASHTO T 283 but that both dry and conditioned indirect tensile strengths are lower for WMA. Reinke (5), in a study of outside aging of WMA samples, reported that initially WMA samples had less binder stiffness than HMA but that after a short period of time the binder properties approached similar levels.

There is a wealth of information available in the literature on constructability, material properties and environmental effects of the different WMA technologies. There

was little literature found on the effect of WMA technologies on the effect of QC/QA properties, most notably laboratory compacted void properties. Some studies have indicated no difference in QC/QA procedures required for WMA technologies and other studies indicate significantly different void properties. The Ohio DOT reported the following reduced lab-molded air voids from their demonstration project on WMA technologies (6):

Table 1 Laboratory Molded Voids from Ohio Study

Mix Type:	Control	Aspha-min	Evotherm	Sasobit
Air Voids (%)				
@ 300°F	3.5	2.4	2.0	1.6
@240°F		3.8	3.2	3.0

Bistor (7) reported a 1.1% reduction in lab-molded air voids between HMA and Green WMA process (foam). Interestingly, Bistor also reported that the ignition furnace reported 0.3% more asphalt cement for the WMA mix compared to the control mix as well (7).

Cowsert (8) reported on the progress of *Task Force 09-01 State Agency WMA Specifications and Project Synthesis*. The research team is in the process of obtaining this report as it should provide valuable insight as to how other agencies are handling QC/QA procedures for WMA mixtures.

OBJECTIVES

The original objectives of this study were to develop testing protocols for three WMA additives, Advera, Sasobit and Evotherm, for mix design and QC/QA procedures. Through an Oklahoma Transportation Center grant, Oklahoma State University was able to purchase a laboratory foaming device, *The Foamer* (Figure 1). The *Foamer* is designed and manufactured to provide a highly accurate and repeatable foamed asphalt samples that are used for Warm Mix Asphalt (WMA), cold mix asphalt and full depth reclamation (FDR) mix designs and performance testing in the laboratory. A one year extension to this project was requested in FY 2011 to included laboratory evaluation of foamed WMA samples using the *Foamer*. The extension was approved for FY 2012.

Figure 1. *The Foamer*.

TASKS

To meet the objectives of this study, the following tasks were accomplished.

Task 1 Literature Review

There is a wealth of literature on WMA technologies. The PI has participated in a recently completed study on moisture damage and performance issues of WMA for the Oklahoma Transportation Center, which contains a literature review of WMA technologies and the WMA Technical Working Group (9) has a web page with a wealth of information on WMA. The literature review for this study will concentrate on laboratory foaming of WMA.

Task 2 Materials

Three WMA additives, Advera, Sasobit, and Evotherm, were obtained from suppliers for evaluation. Foam is the most common WMA procedure used in Oklahoma. When this study was originally proposed foam could not be evaluated in the laboratory; therefore,

two local contractors were selected that could supply plant produced foam mixtures and aggregates. Mixtures that would be foamed in production were selected from these plants for control mixtures (no WMA). Two ODOT S-4 mixtures, one of which required an anti-strip to pass AASHTO T 283, were originally selected for sampling and testing. Neither mixture contained RAP. Production issues arose with the mix that required anti-strip and it was never tested. A replacement mix that could be foamed was identified and sampled in October 2010. The original S-4 mix was tested with WMA additives but was never produced as a foamed mix. Therefore, in November of 2011, a third mix that was produced as a foamed WMA mix was sampled.

Cold feed belt samples of aggregates were obtained for all three mixes precluding the need for mix designs. Plant produced foamed WMA mix was sampled for the two foamed mixes. Asphalt cement for each mix was sampled from the plant.

Task 3 Control Mix Properties

Control samples will be made to the JMF gradation and asphalt content and compacted in the SGC to the N_{design} number of gyrations to determine baseline properties. Control samples will be mixed at 325^{o}F; oven aged for 2 hours at 300^{o}F, and compacted immediately. Loose mix samples will be prepared for maximum theoretical specific gravity (Gmm) testing (AASHTO T 209). A complete voids analysis of the compacted samples will be performed including voids total mix (VTM), voids in mineral aggregate (VMA), voids filled with asphalt (VFA), percent binder absorbed (Pba), percent binder effective (Pbe) and dust proportion (DP).

Task 4 Determination Laboratory Compaction Protocols

WMA samples will be made to the JMF gradation and asphalt content for each mix. Additive rates were based on the supplier's recommendations. Samples will be compacted in the SGC to the N_{design} number of gyrations for the selected mixtures at differing temperatures. All binders will be heated to 325^{o}F. Aggregates will be heated and mixed at 25^{o}F above the selected compaction temperature; oven aged for two hours at the selected compaction temperature and compacted immediately after oven aging. Loose mix samples will be prepared for Gmm testing (AASHTO T 209) using the same mixing and oven aging protocol.

Control samples will be mixed at 325^{o}F; oven aged for 2 hours at 300^{o}F, and compacted immediately. Loose mix samples will be prepared for Gmm testing (AASHTO T 209). A minimum of three replicates for each mix and aggregate will be evaluated. VTM at the N_{design} number of gyrations will be evaluated to determine the equivalent compaction temperature for Advera, Sasobit and Evotherm WMA samples.

The compaction temperature for foamed samples was selected to match compaction temperatures used to produce the plant mixed samples. All binders will be heated to 325^{o}F. Aggregates will be heated and mixed at 25^{o}F above the selected compaction temperature; oven aged for two hours at the selected compaction temperature and compacted immediately after oven aging. Loose mix samples will be prepared for Gmm testing (AASHTO T 209) using the same mixing and oven aging protocol. Most foamed asphalt is produced by injecting 2-5% water, by mass of the binder. Foamed mixes will be made using 3% water.

Task 5 Lab Molded Voids

Once the mixing and compaction temperatures are established, three replicate samples will be mixed and compacted to the N_{design} number of gyrations in the SGC. Loose mix samples will be prepared for maximum theoretical specific gravity (Gmm) testing (AASHTO T 209) and VTM determined for each sample. The data will be analyzed using ANOVA techniques and any additive showing different results from the control mix will be evaluated at extended oven aging times.

Task 6 Rut Depth Testing

Rut depth testing is a part of ODOT's mix design procedure and is being evaluated as a part of their QC/QA procedure (10). Control and WMA samples will be tested using the Hamburg Rut Tester (OHD L-55). Rut depths will be analyzed and if a significant difference exists between control mixes and WMA mixes, WMA samples will be evaluated at additional oven aging times. A protocol for performing Hamburg testing of laboratory prepared foamed WMA mixtures will be developed.

Task 7 Moisture Sensitivity (AASHTO T 283)

AASHTO T 283 is a part of ODOT's mix design procedure. Control and WMA samples will be tested using AASHTO T 283. TSR's and tensile strengths will be analyzed and if a significant difference exists between control mixes and WMA mixes, WMA samples will be evaluated at additional oven aging times. A protocol for performing moisture sensitivity testing of laboratory prepared foamed WMA mixtures will be developed.

Task 8 Plant Produced Mix

One of the concerns with WMA mixes is the effect reheating plant produced samples might have on mix properties. Plant produced Advera, Sasobit and Evotherm is not readily available in Oklahoma. To evaluate these WMA additives, control samples will be mixed at 325^{o}F and oven aged at 300^{o}F. WMA samples will be mixed and oven aged at the temperatures determined in task 3. Samples will be allowed to cool to below 100^{o}F as recommended in the proposed ODOT draft WMA specification. After cooling, the samples will be reheated to the appropriate compaction temperature determined in task 3 and compacted to the N_{design} number of gyrations. Compacted samples will be tested for AASHTO T 283, OHD L-55 (Hamburg) and loose mix samples will be prepared for Gmm testing (AASHTO T 209) using the same mixing and oven aging protocol. The data will be analyzed using ANOVA techniques and a protocol for handling plant produced WMA mixes recommended.

Task 9 Final Report

A final report containing the findings and conclusions from the above tasks will be prepared. The report will contain the results from the analysis as well as a draft test method in AASHTO format, if applicable for WMA additives.

CHAPTER 2
MATERIALS AND TEST PLAN

MATERIALS

WMA Additives

Four different WMA technologies were used to produce WMA mixtures, Advera, Sasobit, Evotherm M-1 and foam. Advera, Sasobit and Evotherm were obtained from suppliers and were introduced into the HMA mixtures using procedures and dosage rates recommended by the suppliers (11,12,13). Foam WMA was produced in the laboratory using the *Foamer* with 3 percent water. Plant produced foamed WMA was obtained from two different local suppliers.

Asphalt Cement

The asphalt cement used for plant production of each mix was obtained from either the plant during production or from the supplier and was used for production of laboratory samples.

Mixes

Foam is the most common WMA procedure used in Oklahoma. When this study was originally proposed foam could not be evaluated in the laboratory; therefore, a local contractor was selected that could supply plant produced foam mixtures and aggregates. Two ODOT S-4 mixtures, one of which required an anti-strip to pass AASHTO T 283, were originally selected for sampling and testing. Neither mixture contained RAP. Production issues arose with the mix requiring anti-strip and it was never sampled. A replacement S-4 mix requiring anti-strip from a different contractor that could produce foamed WMA mix was identified and sampled in October 2010. By the time the *Foamer* was purchased and added to this study, the original S-4 mix was no longer being produced. A third foamed WMA mix (S-5 mix), not requiring anti-strip, was obtained from the original contractor.

Approximately 1,000 pounds of aggregate, sampled off of the cold-feed belt, were obtained for each of the three mixes. Using cold feed belt samples of aggregates

precludes the need for mix designs. Mix design information from the three mixes is shown in Tables 2-4. Mix 1, from Haskell-Lemon, is shown in Table 2 and Mix 2, from APAC-Central-Roberts, is shown in Table 3. Mix design properties are shown in Tables 2 and 3 as well. Laboratory samples were prepared to the cold feed aggregate gradations and mixed with the mix design asphalt content.

TEST PLAN

Control Samples

Control samples were made to the JMF gradation and asphalt content and compacted in the SGC to the N_{design} number of gyrations to determine baseline properties. Control samples were mixed at 325^{o}F, oven aged for 2 hours at 300^{o}F, and compacted immediately after oven aging.

Equivalent Compaction Temperature

To determine the equivalent compaction temperature for Mix 1, samples were prepared using each WMA additive. Additive rates were based on the supplier's recommendations (11,12,13). All binders were heated to 325^{o}F. Aggregates were heated and mixed at 25^{o}F above the selected compaction temperature; oven aged for two hours at the selected compaction temperature and compacted immediately after oven aging. Compaction temperatures evaluated were 225, 250 and 275^{o}F. Loose mix samples were prepared for Gmm testing (AASHTO T 209) using the same mixing and oven aging protocols.

For Mix 2 and 3, a compaction temperature of 265^{o}F was used based on actual production temperatures. All binders were heated to 325^{o}F. Aggregates were heated and mixed at 25^{o}F above the selected compaction temperature; oven aged for two hours at the selected compaction temperature and compacted immediately after oven aging. Loose mix samples were prepared for Gmm testing (AASHTO T 209) using the same mixing and oven aging protocols.

Laboratory and Plant Produced Mix Property Test Matrix

The testing matrix for laboratory molded mix properties for each mix is shown in Table 5. Plant produced mix was not available for Advera, Sasobit and Evotherm so laboratory produced mix was used to simulate plant produced materials. Plant produced foamed WMA was available for Mix 2 and 3. The testing matrix for plant simulated/plant produced mix kept warm, heated to the compaction temperature and compacted is shown in Table 6. The testing matrix for samples allowed to cool below 100^{o}F, heated to the compaction temperature and compacted is shown in Table 7.

Table 2 Mix 1 Reported Mix Design

Number	Aggregate	Producer/Supplier	% Used
1	5/8" Chips	Martin-Marietta (Snyder,OK)	34
2	Stone Sand	Dolese Co., (Cyril, OK)	26
3	Man. Sand	Martin-Marietta (Davis,OK)	15
4	Scrns.	Martin-Marietta (Mill Creek,OK)	10
5	Sand	General Materials Inc., (OKC, OK)	15

Sieve Size	Material 1	2	3	4	5	Comb. Agg.	JMF
	Percent Passing						
3/4 in.	100					100	100
1/2 in.	92					97	97
3/8 in.	71	100	100	100	100	90	90
No. 4	22	97	96	79	99	70	70
No. 8	5	64	60	52	99	47	47
No. 16	3	40	34	35	98	35	35
No. 30	2	27	20	24	92	27	27
No. 50	2	22	11	16	61	19	19
No. 100	2	14	6	11	15	9	9
No. 200	1.2	4.6	3.6	7.2	2	3.2	3.2
AC (%)							5.1

Reported Mix Properties at Optimum Asphalt Content	
Gse	2.663
Gsb	2.630
Gmm	2.458
Gmb	2.360
VTM	4.0
VMA	14.9
VFA	73.0
DP	0.7
Pba	0.5%
Pbe	4.7%

Table 3 Mix 2 Reported Mix Design

Number	Aggregate	Producer/Supplier	% Used
1	#67 Rock	Arkhola S & G (Okay, OK)	23
2	3/8" Chips	Arkhola S & G (Zeb, OK)	36
3	Washed Scrns	Arkhola S & G (Zeb, OK)	24
4	Scrns.	Arkhola S & G (Okay, OK)	17
	Anti-Strip	Perma-Tac Plus Akzo Nobel (Waco, TX)	0.05%

Sieve	Material				Comb.	
Size	1	2	3	4	Agg.	JMF
	Percent Passing					
3/4 in.	100				100	100
1/2 in.	64	100			92	92
3/8 in.	25	99		100	82	82
No. 4	5	44	100	89	56	56
No. 8	3	7	88	57	34	34
No. 16	2	5	54	36	21	21
No. 30	2	4	34	24	14	14
No. 50	2	3	25	18	11	11
No. 100	2	3	17	15	8	8
No. 200	1.5	2	11.5	11.0	5.7	5.7
AC (%)						5.2

Reported Mix Properties at Optimum Asphalt Content	
Gse	2.600
Gsb	2.550
Gmm	2.410
Gmb	2.314
VTM	4.0
VMA	14
VFA	71.3
DP	1.28
Pba	0.8%
Pbe	4.5%

Table 4 Mix 3 Reported Mix Design

Number	Aggregate	Producer/Supplier	% Used
1	1/4" Chips	Martin-Marietta (Mill Creek,OK)	30
3	Man. Sand	Martin-Marietta (Davis,OK)	17
4	Scrns.	Martin-Marietta (Richard Spur,OK)	38
5	Sand	General Materials Inc., (OKC, OK)	15

Sieve	Material				Comb.	
Size	1	2	3	4	Agg.	JMF
	Percent Passing					
1/2 in.	100				100	100
3/8 in.	99	100	100	100	100	100
No. 4	39	91	79	98	72	72
No. 8	10	57	47	76	42	42
No. 16	7	32	28	47	25	25
No. 30	5	18	19	27	16	16
No. 50	4	10	13	11	9	9
No. 100	2	5	10	4	6	6
No. 200	1.2	3.3	8.6	2.0	4.5	4.5
AC (%)						5.2

Reported Mix Properties at Optimum Asphalt Content	
Gse	2.710
Gsb	2.654
Gmm	2.492
Gmb	2.392
VTM	4.0
VMA	14.6
VFA	72.5
DP	1.01
Pba	0.8%
Pbe	4.5%

Table 5 Mix 1 Lab Molded (Mix Design) Test Matrix

Mix	Mixing Temp.		Comp. Temp	Oven Age Time	AASHTO T 209	Lab Molded Voids	AASHTO T 283	Hamburg
	Asphalt	Agg.						
Mix 1								
Control	325 F	325 F	300 F	2 hrs	3 samples	3 samples	1-set	4-pills
Sasobit	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Sasobit	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Advera	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Advera	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Evotherm	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Evotherm	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Mix 2								
Control	325 F	325 F	300 F	2 hrs	3 samples	3 samples	1-set	4-pills
Sasobit	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Sasobit	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Advera	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Advera	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Evotherm	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Evotherm	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Foam	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Foam	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills
Mix 3								
Control	325 F	325 F	300 F	2 hrs	3 samples	3 samples	1-set	4-pills
Foam	325 F	290 F	265 F	2 hrs	3 samples	3 samples	1-set	4-pills
Foam	325 F	290 F	265 F	4 hrs	3 samples	3 samples	1-set	4-pills

Table 6 Test Matrix Field Samples Kept Warm

Additive	Compaction Temperature	Kept Warm			
		AASHTO T 209	Lab Molded Voids	AASHTO T 283	Hamburg OHD L-55
Mix 2					
Control	300 F	3 samples	3 samples	1-set	4-pills
Foam	265 F	3 samples	3 samples	1-set	4-pills
Mix 3					
Control	300 F	3 samples	3 samples	1-set	4-pills
Foam	265 F	3 samples	3 samples	1-set	4-pills

Table 7 Test Matrix Field Samples Cooled Below 100^{o}F

Additive	Compaction Temperature	Reheat Below 100 F			
		AASHTO T 209	Lab Molded Voids	AASHTO T 283	Hamburg OHD L-55
Mix 1					
Sasobit	265 F	3 samples	3 samples	1-set	4-pills
Advera	265 F	3 samples	3 samples	1-set	4-pills
Evotherm	265 F	3 samples	3 samples	1-set	4-pills
Mix 2					
Control	300 F	3 samples	3 samples	1-set	4-pills
Sasobit	265 F	3 samples	3 samples	1-set	4-pills
Advera	265 F	3 samples	3 samples	1-set	4-pills
Evotherm	265 F	3 samples	3 samples	1-set	4-pills
Foam	265 F	3 samples	3 samples	1-set	4-pills
Mix 3					
Control	300 F	3 samples	3 samples	1-set	4-pills
Foam	265 F	3 samples	3 samples	1-set	4-pills

CHAPTER 3
TEST RESULTS

CONTROL SAMPLES

Control samples were made to the JMF gradation and asphalt content and compacted in the SGC to the N_{design} number of gyrations to determine baseline properties. Control samples were mixed at 325^{o}F, oven aged for 2 hours at 300^{o}F, and compacted immediately. At the same time, samples were prepared for Gmm testing (AASHTO T 209). The results are shown in Table 8.

Table 8 Laboratory Compacted Control Mix Properties

325 F Mix Temperature			
300 F 2-hour Oven Aging			
300 F Compaction Temperature			
Mix Property	**Mix 1**	**Mix 2**	**Mix 3**
Gmm	2.454	2.402	2.480
Gmb	2.338	2.298	2.355
VTM	4.7%	4.3%	5.0%
VMA	15.6%	14.6%	15.9%
VFA	69.8%	70.3%	68.3%
Pb	5.1%	5.2%	5.2%
Pba	0.4%	0.6%	0.6%
Pbe	4.7%	4.6%	4.7%
DP	0.7	1.2	1.0

EQUIVALENT COMPACTION TEMPERATURE

An equivalent compaction temperature that would match the control mix VTM was used to establish mixing and compaction temperatures for Mix 1. To determine equivalent compaction temperature for Mix 1, samples were prepared using each WMA additive. Additive rates were based on the supplier's recommendations.

All binders were heated to 325^{o}F and aggregates were heated and mixed at 25^{o}F above the selected compaction temperature; oven aged for two hours at the selected compaction temperature and compacted immediately after oven aging. Loose mix samples were prepared for Gmm testing (AASHTO T 209) using the same mixing and

oven aging protocol. The results are shown in Table 9. Figure 2 shows the selected equivalent compaction temperature for each additive.

Table 9 Mix 1 WMA Lab Molded Voids

Mixing Temp. (F)	Compaction Temp. (F)	Advera	Sasobit	Evotherm
		VTM (%)		
250	225	5.2	5.0	5.1
275	250	5.2	4.9	5.0
300	275	4.2	4.4	4.4

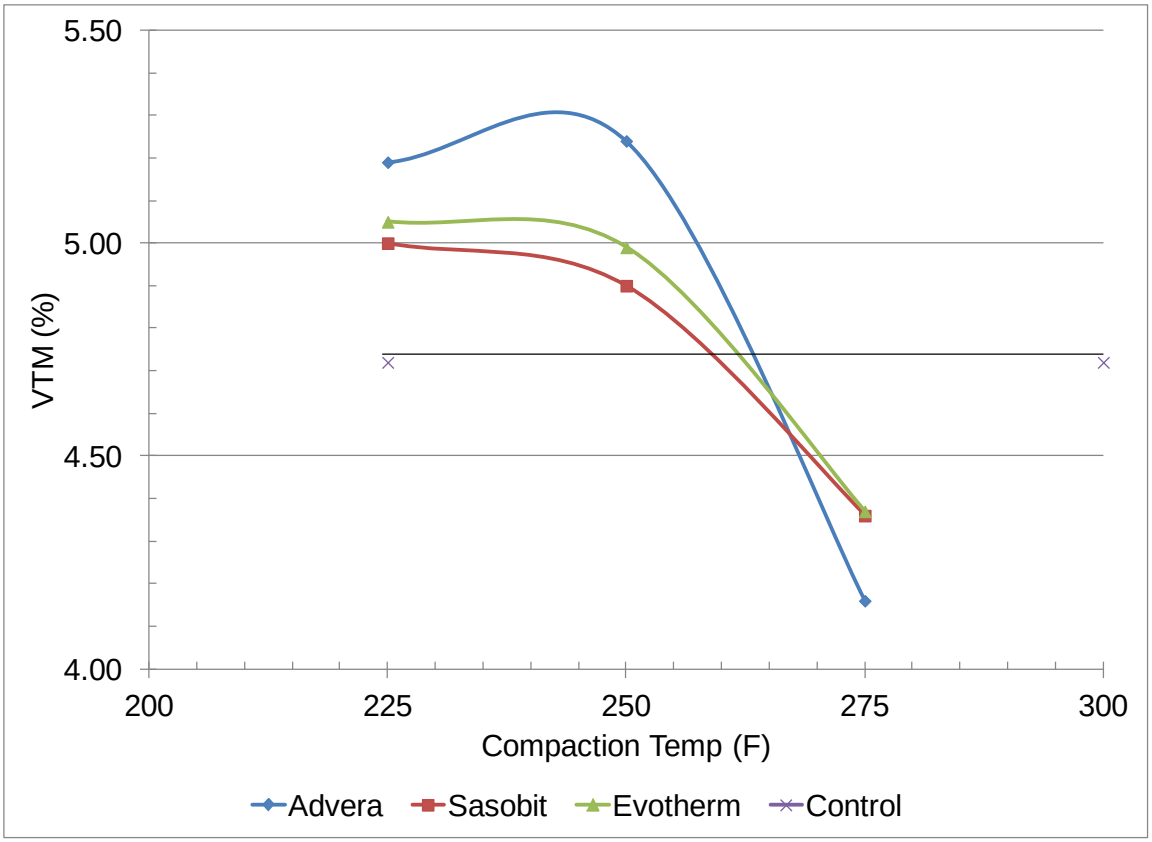

Figure 2 Mix 1 equivalent WMA compaction temperatures, based on VTM.

Mix 2 and 3 used the plant produced compaction temperature of 265^{o}F. All binders were heated to 325^{o}F. Aggregates were heated and mixed at 25^{o}F above the selected compaction temperature (290^{o}F); oven aged for two hours at the compaction temperature and compacted immediately after oven aging. Loose mix samples were

prepared for Gmm testing (AASHTO T 209) using the same mixing and oven aging protocols.

LABORATORY SAMPLES

Samples were mixed with WMA additives and compacted and tested in the laboratory. Samples were tested for lab molded bulk specific gravity (OHD L-14), maximum theoretical specific gravity (AASHTO T 209), resistance to moisture induced damage (AASHTO T 283) and rutting resistance (OHD L-55). The results for the Mix 1 and 2 samples made with Advera, Sasobit and Evotherm are shown in Tables 10 and 11, respectively. The results for the Mix 2 and 3 foam WMA samples are presented in Table 12.

PLANT PRODUCED/SIMULATED SAMPLES

Plant produced samples were not available for the Advera, Sasobit and Evotherm WMA additives. To simulate plant produced samples, mixes were mixed, oven aged, allowed to cool to below 100^{o}F and then reheated to the compaction temperature and compacted. Samples were tested for lab molded bulk specific gravity (OHD L-14), maximum theoretical specific gravity (AASHTO T 209), resistance to moisture induced damage (AASHTO T 283) and rutting resistance (OHD L-55). The results for the Mix 1 and 2 samples made with Advera, Sasobit and Evotherm are shown in Table 13. Plant produced mix was available for foamed WMA. The results for the Mix 2 and 3 foam WMA samples are presented in Table 14.

TABLE 10 Mix 1 Laboratory Mix Properties

WMA Additive	Sample	Age	AASHTO T 283 Dry ITS (psi)	AASHTO T 283 Cond. CITS (psi)	AASHTO T 283 TSR	Gmb	Gmm	OHD L-55 Rut Depth 10,000 Passes (mm)
Control	1	2				2.340	2.455	12.4
Control	2	2				2.336	2.457	6.8
Control	3	2	90.8	77.2	0.85	2.339	2.451	
Control	1	4						3.3
Control	2	4						3.2
Advera	1	2	118.8	88.0		2.373	2.444	11.6
Advera	2	2	122.5	94.0		2.364	2.438	12.2
Advera	3	2	117.7	105.3	0.80	2.374	2.445	
Advera	1	4	115.9	77.2		2.327	2.465	3.2
Advera	2	4	107.0	60.9		2.334	2.457	3.3
Advera	3	4	126.6	65.7	0.58	2.323	2.453	
Sasobit	1	2	110.3	100.8		2.34	2.458	13.1
Sasobit	2	2	113.5	102.3		2.34	2.436	13.6
Sasobit	3	2	117.1	104.2	0.90	2.35	2.449	
Sasobit	1	4	140.4	82.2		2.33	2.441	5.6
Sasobit	2	4	149.3	84.1		2.32	2.473	5.0
Sasobit	3	4	165.5	87.1	0.56	2.32	2.450	
Evotherm	1	2	111.6	97.1		2.344	2.459	1.8
Evotherm	2	2	118.3	110.3		2.337	2.424	2.4
Evotherm	3	2	115.5	107.2	0.91	2.345	2.464	
Evotherm	1	4	114.7	99.7		2.315	2.465	3.3
Evotherm	2	4	118.6	88.4		2.338	2.458	3.2
Evotherm	3	4	120.7	98.4	0.81	2.304	2.450	

TABLE 11 Mix 2 Laboratory Mix Properties

WMA Additive	Sample	Age	AASHTO T 283 Dry ITS (psi)	AASHTO T 283 Cond. CITS (psi)	AASHTO T 283 TSR	Gmb	Gmm	OHD L-55 Rut Depth 10,000 Passes (mm)
Control	1	2	172.3	114.7		2.352	2.451	8.9
Control	2	2	178.6	94.5		2.367	2.452	6.6
Control	3	2	172.2	106.1	0.60	2.350	2.452	
Advera	1	2	106.5	44.5		2.300	2.417	18.8
Advera	2	2	111.5	49.7		2.300	2.405	24.4
Advera	3	2	116.3	52.0	0.44	2.297	2.413	
Advera	1	4	129.8	54.9		2.332	2.426	17.4
Advera	2	4	114.2	60.3		2.277	2.421	15.8
Advera	3	4	141.5	67.6	0.47	2.279	2.420	
Sasobit	1	2	114.6	69.2		2.294	2.399	20.5
Sasobit	2	2	124.7	58.6		2.291	2.403	19.7
Sasobit	3	2	118.9	62.4	0.53	2.286	2.397	
Sasobit	1	4	126.8	73.2		2.296	2.417	14.2
Sasobit	2	4	121.9	67.1		2.298	2.422	13.2
Sasobit	3	4	120.6	71.5	0.57	2.294	2.421	
Evotherm	1	2	107.1	71.4		2.296	2.404	19.9
Evotherm	2	2	116.2	77.4		2.295	2.403	21.9
Evotherm	3	2	104.2	77.4	0.69	2.297	2.401	
Evotherm	1	4	110.3	80.1		2.282	2.424	11.5
Evotherm	2	4	105.4	77.4		2.295	2.421	16.2
Evotherm	3	4	109.9	83.4	0.74	2.283	2.414	

TABLE 12 Mix 2 and 3 Foamed Laboratory Mix Properties

Mix	WMA Additive	Sample	Age	AASHTO T 283 Dry ITS (psi)	AASHTO T 283 Cond. CITS (psi)	AASHTO T 283 TSR	Gmb	Gmm	OHD L-55 Rut Depth 10,000 Passes (mm)
2	Control	1	2	172.3	114.7	.	2.352	2.451	8.9
2	Control	2	2	178.6	94.5	.	2.367	2.452	6.6
2	Control	3	2	172.2	106.1	0.63	2.350	2.452	.
2	Foam	1	2	105.5	56.7		2.307	2.401	18
2	Foam	2	2	105.1	43.3		2.297	2.403	18
2	Foam	3	2	101.1	48.2	0.48	2.298	2.404	
2	Foam	1	4	118.6	61.9		.	.	12.2
2	Foam	2	4	116.1	63.2		.	.	12
2	Foam	3	4	106.2	68.3	0.57	.	.	
2	Foam	1	16	118.8	78.5		.	.	12.2
2	Foam	2	16	117.2	63.6		.	.	8.3
2	Foam	3	16	116.3	68	0.60	.	.	
3	Control	1	2	117.7	107.7		2.356	2.481	5.3
3	Control	2	2	118.1	100.4		2.356	2.481	12.8
3	Control	3	2	136.3	100.8	0.83	2.354	2.479	
3	Foam	1	2	99.7	63		2.361	2.431	F
3	Foam	2	2	94.3	73.2		2.326	2.444	F
3	Foam	3	2	95.5	71.7	0.72	2.342	2.445	
3	Foam	1	4	112.4	85.9		2.352	2.444	
3	Foam	2	4	113.9	83.1		2.384	2.448	6.0
3	Foam	3	4	109.2	82.8	0.75	2.377	2.433	6.2

TABLE 13 Mix 1 and 2 Field Simulated Mix Properties

Mix	WMA Additive	Sample	Age	AASHTO T 283 Dry ITS (psi)	AASHTO T 283 Cond. CITS (psi)	AASHTO T 283 TSR	Gmb	Gmm	OHD L-55 Rut Depth 10,000 Passes (mm)
1	Control	1	CO	127.5	113.0				
1	Control	2	CO	137.9	113.7				
1	Control	3	CO	126.9	107.7	0.85			
1	Advera	1	CO	118.6	114.8		2.340	2.446	3.6
1	Advera	2	CO	123.8	109.2		2.338	2.433	2.2
1	Advera	3	CO	124.6	94.6	0.87	2.338	2.440	
1	Sasobit	1	CO	131.6	95.1		2.35	2.462	3.4
1	Sasobit	2	CO	119.4	109.5		2.35	2.460	5.8
1	Sasobit	3	CO	143	115.6	0.81	2.35	2.469	
1	Evotherm	1	CO	107.0	107.3		2.346	2.461	2.2
1	Evotherm	2	CO	142.4	105.6		2.341	2.463	3.8
1	Evotherm	3	CO	133.3	102.4	0.82	2.341	2.453	
2	Control	1	CO	141.2	112.5		2.285	2.414	4.7
2	Control	2	CO	146.0	116.3		2.273	2.404	4.7
2	Control	3	CO	148.5	111.5	0.78	2.291	2.403	
2	Advera	1	CO	109.8	55.1		2.303	2.413	11.0
2	Advera	2	CO	103.0	56.7		2.287	2.412	16.1
2	Advera	3	CO	95.1	55.9	0.55	2.298	2.400	
2	Sasobit	1	CO	99.8	78.9		2.308	2.398	7.9
2	Sasobit	2	CO	99.7	74.5		2.290	2.400	
2	Sasobit	3	CO	102.7	76.0	0.76	2.320	2.403	
2	Evotherm	1	CO	104.3	68.5		2.310	2.404	7.3
2	Evotherm	2	CO	101.3	78.2		2.297	2.408	12.2
2	Evotherm	3	CO	99.9	86.6	0.76	2.301	2.403	

TABLE 14 Mix 2 and 3 Plant Produced Mix Properties

Mix	WMA Additive	Sample	Age	AASHTO T 283 Dry ITS (psi)	AASHTO T 283 Cond. CITS (psi)	AASHTO T 283 TSR	Gmb	Gmm	OHD L-55 Rut Depth 10,000 Passes (mm)
2	Control	1	CO	141.2	112.5		2.285	2.414	4.7
2	Control	2	CO	146.0	116.3		2.273	2.404	4.7
2	Control	3	CO	148.5	111.5	0.78	2.291	2.403	
2	Foam	1	CO	155	130.6		2.394	2.44	4.5
2	Foam	2	CO	194.6	131.5		2.391	2.444	5.5
2	Foam	3	CO	200.2	136.1	0.72	2.388	2.442	
2	Foam	1	R	113.3	68.6		2.328	2.425	18
2	Foam	2	R	118.5	83.4		2.342	2.445	18
2	Foam	3	R	107.1	70.2	0.66	2.342	2.438	
3	Foam	1	CO	176.3	126.2		2.375	2.481	7.6
3	Foam	2	CO	151.3	128.1		2.38	2.485	3.3
3	Foam	3	CO	155.5	132.8	0.80	2.385	2.485	
3	Foam	1	R	139.3	128.6		2.364	2.483	13.6
3	Foam	2	R	138.3	136.9		2.364	2.478	11.1
3	Foam	3	R	144.2	136.8	0.95	2.357	2.482	

CHAPTER 4
ANALYSIS OF WMA ADDITIVES

TEST PLAN

Each WMA additive was evaluated for its effect on mix design properties and field control test properties. Mix design properties included lab molded voids, maximum theoretical specific gravity, TSR and tensile strengths, and Hamburg rut depths. Field simulated test properties included the same tests as mix design properties. In addition, TSR and Hamburg results were evaluated to determine the effect of sample reheating on mix properties. Table 15 shows the codes used and the mix conditioning protocols used. The first letter is the material or WMA additive. The second or second and third symbol represents the aging condition.

TABLE 15 Identification Code, WMA Additives

1st Symbol	Description	2nd Symbol(s)	Description
Laboratory Produced Samples			
C	Control	2	Heat asphalt, aggregate 325°F and mix. Oven age 2 hrs 300°F and compact
		4	Heat asphalt, aggregate 325°F and mix. Oven age 4 hrs 300°F and compact
A S E	Advera, Sasobit Evotherm	2	Heat asphalt 325°F, aggregate 290°F and mix. Oven age 2 hrs 265°F and compact.
		4	Heat asphalt 325°F, aggregate 290°F and mix. Oven age 4 hrs 265°F and compact.
Field Simulated Samples			
C	Control	CO	Heat asphalt, aggregate 325°F and mix. Oven age 2 hrs. Allow to cool below 100°F (overnight), reheat to 300°F and compact.
A S E	Advera, Sasobit Evotherm	CO	Heat asphalt, aggregate 325°F and mix. Oven age 2 hrs. Allow to cool below 100°F (overnight), reheat to 265°F and compact.

ADVERA

WMA samples were made with Advera from Mixes 1 and 2. Advera WMA samples were tested for laboratory produced mix properties and field simulated mix properties. Plant

produced Advera samples were not available. Control mixes were tested at 2 and 4 hour oven aging and after allowing the 2-hour oven aged mix to cool below 100^{o}F (overnight), reheat to 265^{o}F and compact.

Specific Gravity

Results of the lab molded bulk specific gravity testing and maximum specific gravity testing are shown in Figures 3 and 4, respectively. To determine if the differences in mean Gmb and Gmm were statistically significant, an analysis of variance (ANOVA) was performed on the curing condition by mix type. There was a significant difference in curing condition for Gmb and Gmm, by mix, at a level of significance exceeding 95% ($\alpha < 0.05$). To determine which means were statistically different, Duncan's Multiple Range Test was performed. The results are shown in Table 16.

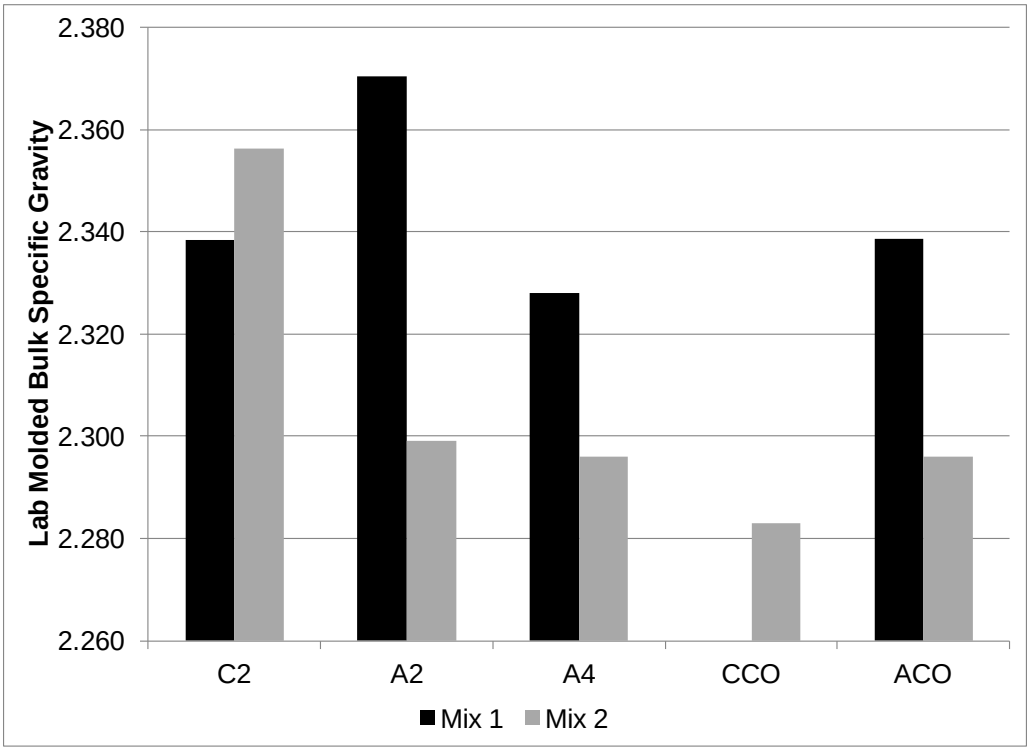

Figure 3 Effect of curing conditions on bulk specific gravity, Advera WMA.

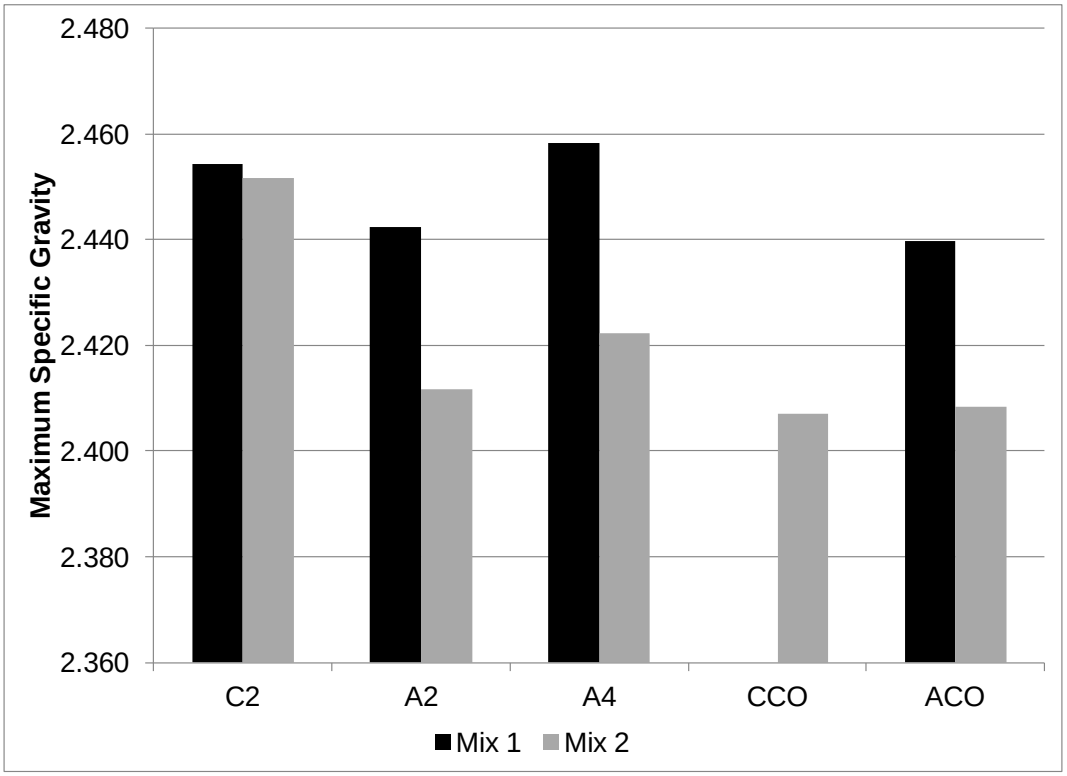

Figure 4 Effect of curing conditions on maximum specific gravity, Advera WMA.

TABLE 16 Duncan's Multiple Range Test on Specific Gravity, Advera WMA

Mix 1				Mix 2			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Gmb							
A	2.370	3	A2	A	2.356	3	C2
B	2.339	3	ACO	B	2.299	3	A2
B	2.339	3	C2	B	2.296	3	A4
C	2.328	3	A4	B	2.296	3	ACO
				B	2.283	3	CCO
Gmm							
A	2.458	3	A4	A	2.452	3	C2
A	2.454	3	C2	B	2.422	3	A4
B	2.442	3	A2	C	2.412	3	A2
B	2.440	3	ACO	C	2.408	3	ACO
				C	2.407	3	CCO

As shown in Table 16, no WMA laboratory aging procedure matched the control bulk specific gravity. For both mixes the 4-hour aged Advera samples came the closest to the control Gmb. Allowing the Advera WMA to cool below 100^{o}F before recompaction

gave statistically similar Gmb results for the Mix 1 control mix and for the recompacted Mix 2 control sample.

For maximum specific gravity, the Mix 1 4-hour aged and recompacted Advera samples were statistically similar to the control mix. For Mix 2 the 4-hour Advera sample was closest to the control samples and the recompacted control and Advera samples were statistically similar.

AASHTO T 283 Testing

Tensile Strength

Results of dry and conditioned indirect tensile strength testing are shown in Figures 5 and 6, respectively. An ANOVA on dry and conditioned indirect tensile strengths was performed on curing condition, by mix type, to determine if the difference in means was statistically significant. There was a significant difference in dry and conditioned indirect tensile strength for curing condition, by mix, at a level of significance exceeding 95% ($\alpha < 0.05$). Duncan's Multiple Range Test was performed to determine which means were significantly different. The results are shown in Table 17.

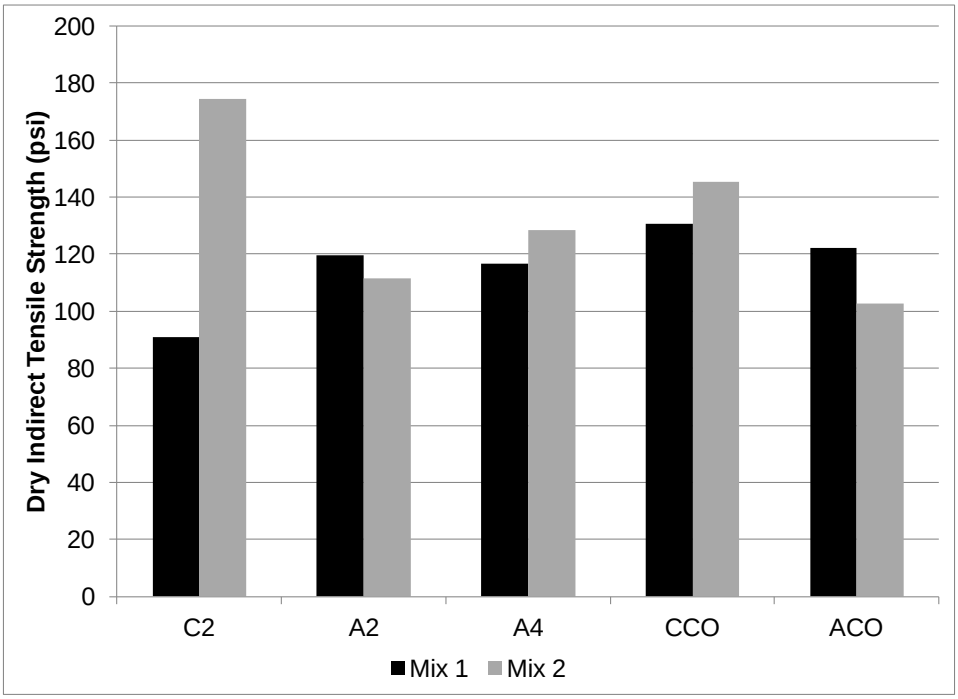

Figure 5 Effect of curing conditions on dry tensile strength, Advera WMA.

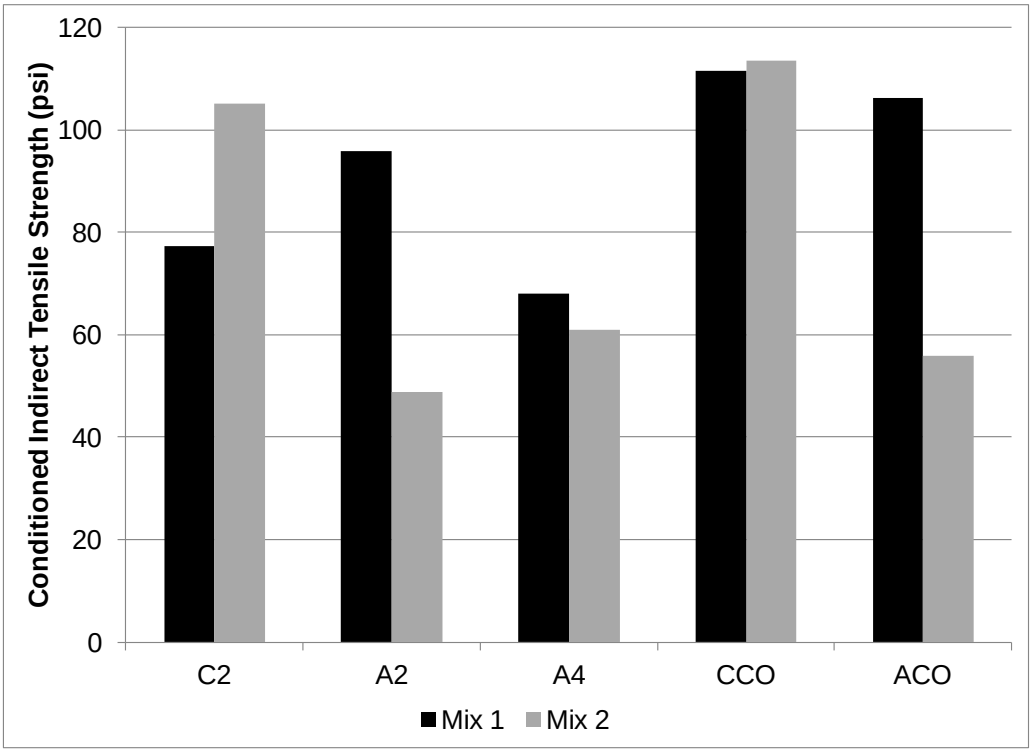

Figure 6 Effect of curing conditions on conditioned tensile strength, Advera WMA.

TABLE 17 Duncan's Multiple Range Test on Tensile Strength, Advera WMA

Mix 1				Mix 2			
Grouping	**Mean**	**N**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Dry Indirect Tensile Strength (psi)							
A	130.8	3	CCO	A	174.4	3	C2
A	122.3	3	ACO	B	145.2	3	CCO
A	119.7	3	A2	C	128.5	3	A4
A	116.5	3	A4	D	111.4	3	A2
B	90.8	1	C2	D	102.6	3	ACO
Conditioned Indirect Tensile Strength (psi)							
A	111.5	3	CCO	A	113.4	3	CCO
A	106.2	3	ACO	A	105.1	3	C2
A	95.8	3	A2	B	60.9	3	A4
B	77.2	1	C2	B C	55.9	3	ACO
B	67.9	3	A4	C	48.7	3	A2

No Advera samples were statistically similar to the control dry tensile strength. The 4-hour cure Advera samples were the closest. For conditioned tensile strength, the 4-hour cure Advera samples were statistically similar to the control for Mix 1 and closest to the control for Mix 2. For reheated samples the Mix 1 tensile strengths were similar to the control reheated samples but the same was not true for Mix 2.

Tensile Strength Ratio

The results of the tensile strength ratio testing from AASHTO T 283 are shown in Figure 7. Replicate samples for AASHTO T 283 were not performed. Therefore, to determine if TSRs between the control mix and Advera WMA samples should be considered similar, the single operator acceptable range of two TSR results of 0.093, as reported by Azari, (14) was utilized. Table 18 shows the TSR for each curing condition and the difference in TSR between the control mix and each curing condition.

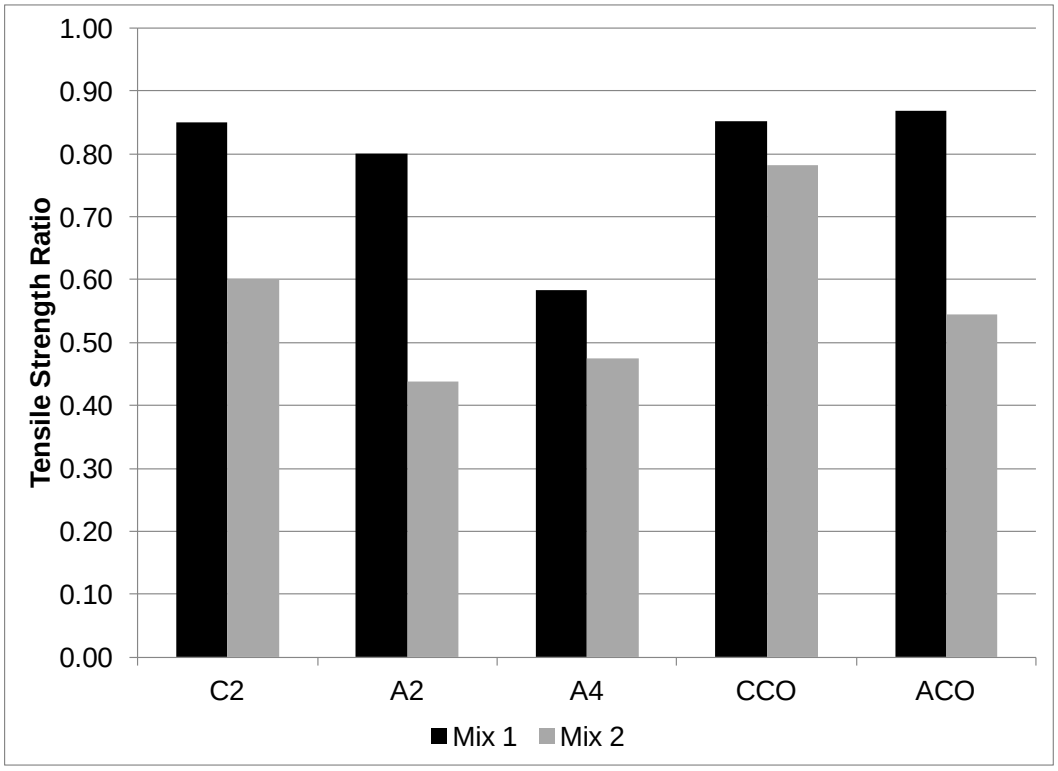

Figure 7 Effect of curing conditions on AASHTO T 283 TSR, Advera WMA.

TABLE 18 Summary of TSR Results, Advera WMA

Mix 1				Mix 2			
TSR	**Curing**	**Difference From Control**	**Similar (S) Different (D)**	**TSR**	**Curing**	**Difference From Control**	**Similar (S) Different (D)**
0.85	C2	*		0.60	C2	*	
0.80	A2	0.05	S	0.44	A2	0.16	D
0.58	A4	0.27	D	0.47	A4	0.13	D
0.87	ACO	-0.02	S	0.55	ACO	0.05	S
0.85	CCO	0.00	S	0.78	CCO	-0.18	D

For Mix 1, TSRs were similar for the control and 2-hour Advera samples and for the reheated samples. For Mix 2 the control TSR was similar to the reheated Advera sample.

Hamburg Rut Test

Results of the mean rut depths from the Hamburg Rut Test (OHD L-55) are shown in Figure 8. The ANOVA indicated a significant difference in mean rut depth for the different curing conditions, by mix, at a level of significance exceeding 95% (alpha < 0.05). Duncan's Multiple Range Test was performed to determine which means were statistically different. The results are shown in Table 19.

TABLE 19 Duncan's Multiple Range Test on Hamburg Rut Depths, Advera WMA

Mix 1				Mix 2			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Mean Rut Depth at 10,000 Passes (mm)							
A	11.90	2	A2	A	21.60	2	A2
A	9.60	2	C2	A B	16.60	2	A4
B	3.25	2	A4	B C	13.55	2	ACO
B	2.90	2	ACO	C D	7.75	2	C2
				D	4.70	2	CCO

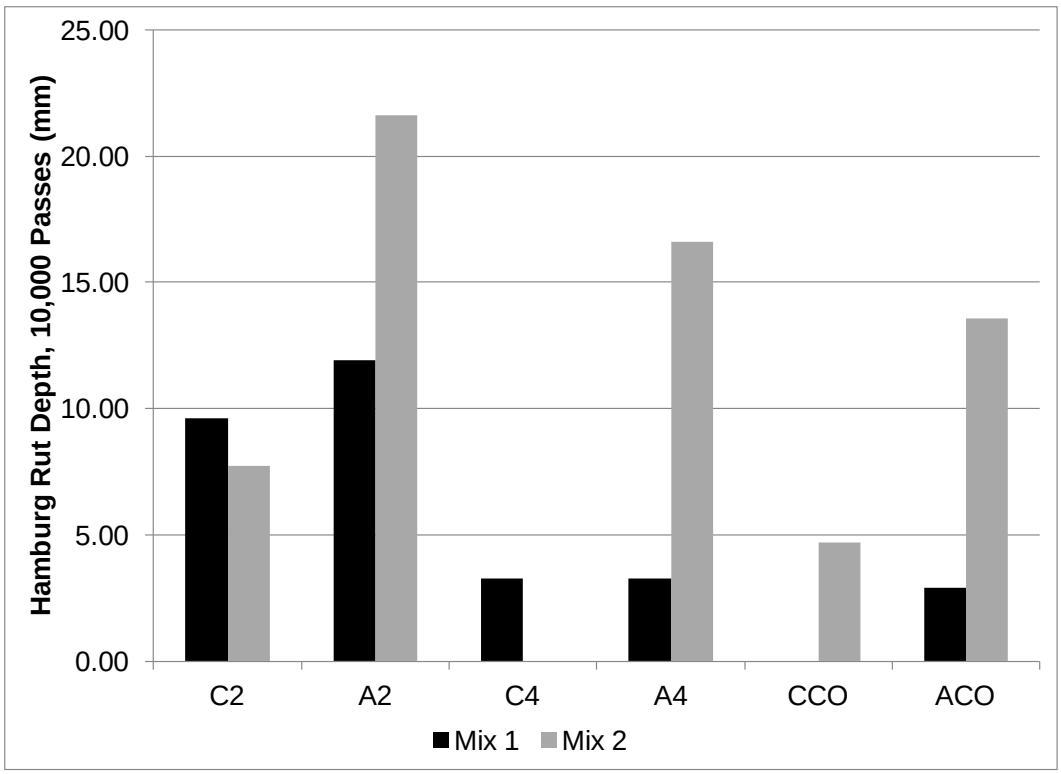

Figure 8 Effect of curing conditions on Hamburg rut depths, Advera WMA.

The Hamburg test (OHD L-55) does not appear to be very repeatable with large differences in rut depths resulting in statistically similar results. For Mix 1, a 4-hour cure and reheating the Advera samples reduced the rut depth to below the control mix. For Mix 2 all Advera samples rutted more than the control mix.

SASOBIT

WMA samples were made with Sasobit from Mixes 1 and 2. Sasobit WMA samples were tested for laboratory produced mix properties and field simulated mix properties. Plant produced Sasobit samples were not available.

Specific Gravity

Results of the lab molded bulk specific gravity testing and maximum specific gravity testing are shown in Figures 9 and 10, respectively. The same analysis procedure followed with Advera was used with Sasobit. An ANOVA was performed on curing conditions for Gmb and Gmm, by mix type, to determine if the means were statistically

different. At a level of significance of 95% (α = 0.05), there was a significant difference in curing condition for Gmb by mix. However, for Gmm, there was a significant difference in means for Mix 2 but not for Mix 1. To determine which means were statistically different, Duncan's Multiple Range Test was performed. The results are shown in Table 20.

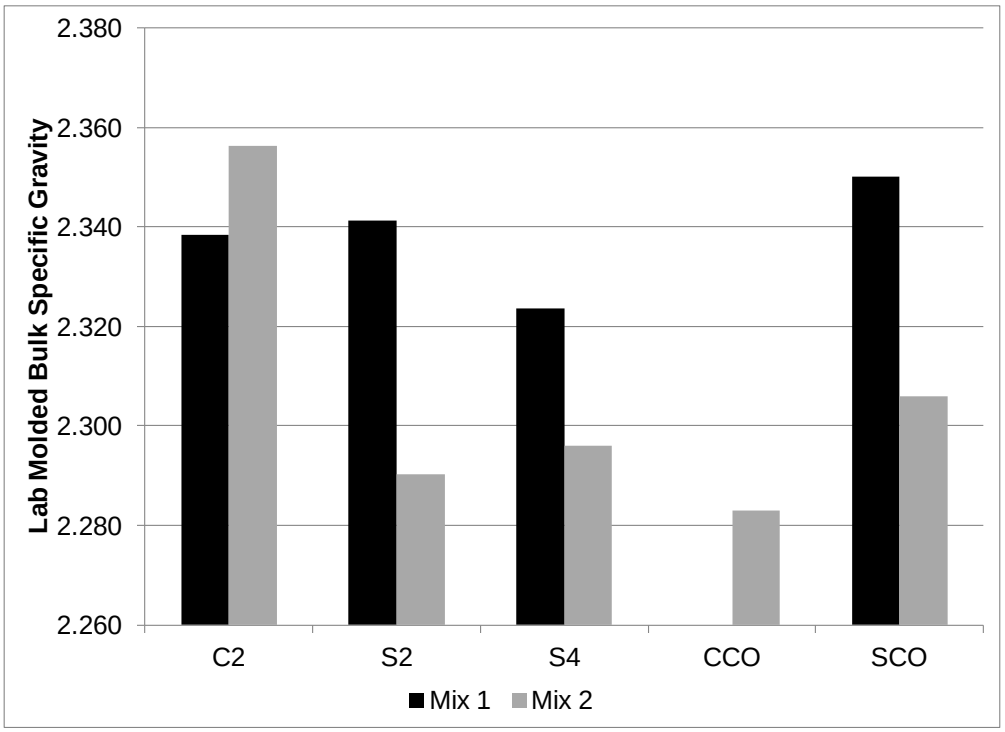

Figure 9 Effect of curing conditions on bulk specific gravity, Sasobit WMA.

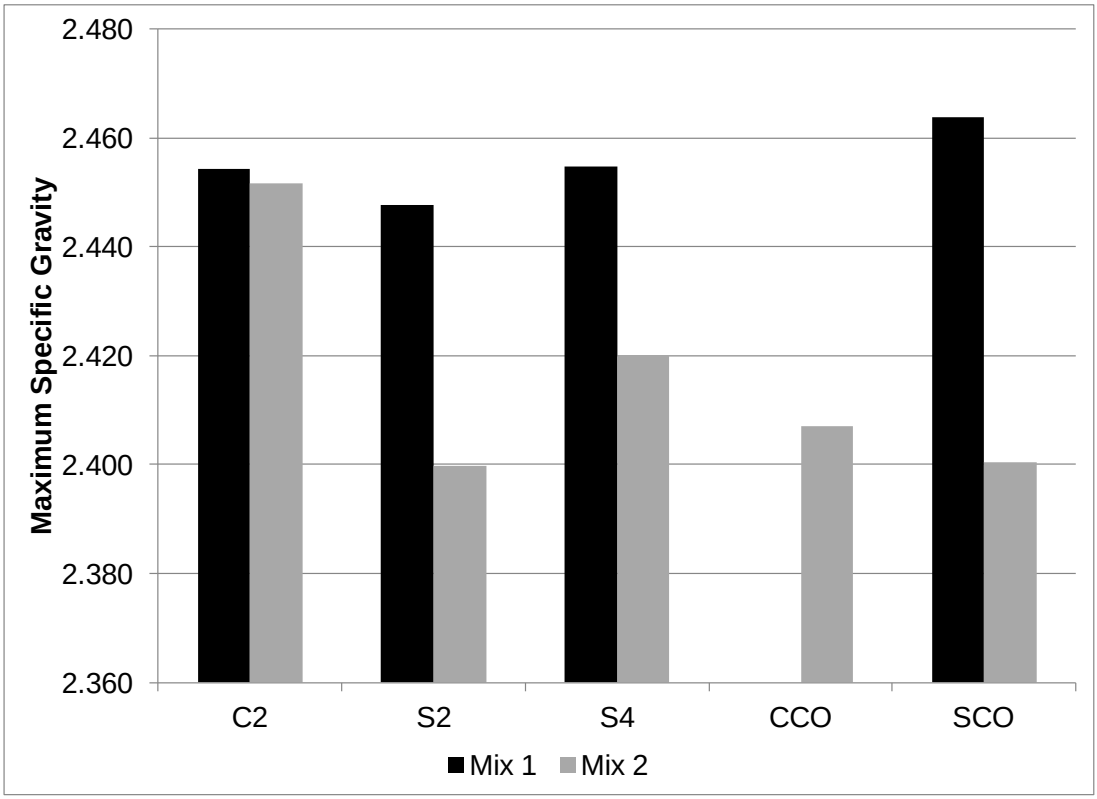

Figure 10 Effect of curing conditions on maximum specific gravity, Sasobit WMA.

TABLE 20 Duncan's Multiple Range Test on Specific Gravity, Sasobit WMA

Mix 1				Mix 2			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Gmb							
A	2.350	3	SCO	A	2.356	3	C2
B	2.341	3	S2	B	2.306	3	SCO
B	2.338	3	C2	B C	2.296	3	S4
C	2.324	3	S4	B C	2.290	3	S2
				C	2.283	3	CCO
Gmm							
A	2.464	3	SCO	A	2.452	3	C2
A	2.455	3	S4	B	2.420	3	S4
A	2.454	3	C2	C	2.407	3	CCO
A	2.448	3	S2	D	2.400	3	SCO
				D	2.400	3	S2

For Mix 1, the 2-hour cure and control samples had similar Gmb values. Reheating and recompacting resulted in the highest Gmb. For Mix 2, the control and recompacted Sasobit samples were similar with the 4-hour cure being the closest to the

control mix. All Gmm samples were statistically similar for Mix 1 with the 4-hour cure being the closest to the control mix for Mix 2.

AASHTO T 283 Testing

Tensile Strength

Results of dry and conditioned indirect tensile strength test results are shown in Figures 11 and 12, respectively. To determine if the differences in mean dry and conditioned indirect tensile strengths were statistically significant, an ANOVA was performed on the curing condition by mix type. There was a significant difference in curing condition at a level of significance of 95% ($\alpha = 0.05$) for dry and conditioned indirect tensile strength, by mix. To determine which means were statistically different, Duncan's Multiple Range Test was performed. The results are shown in Table 21.

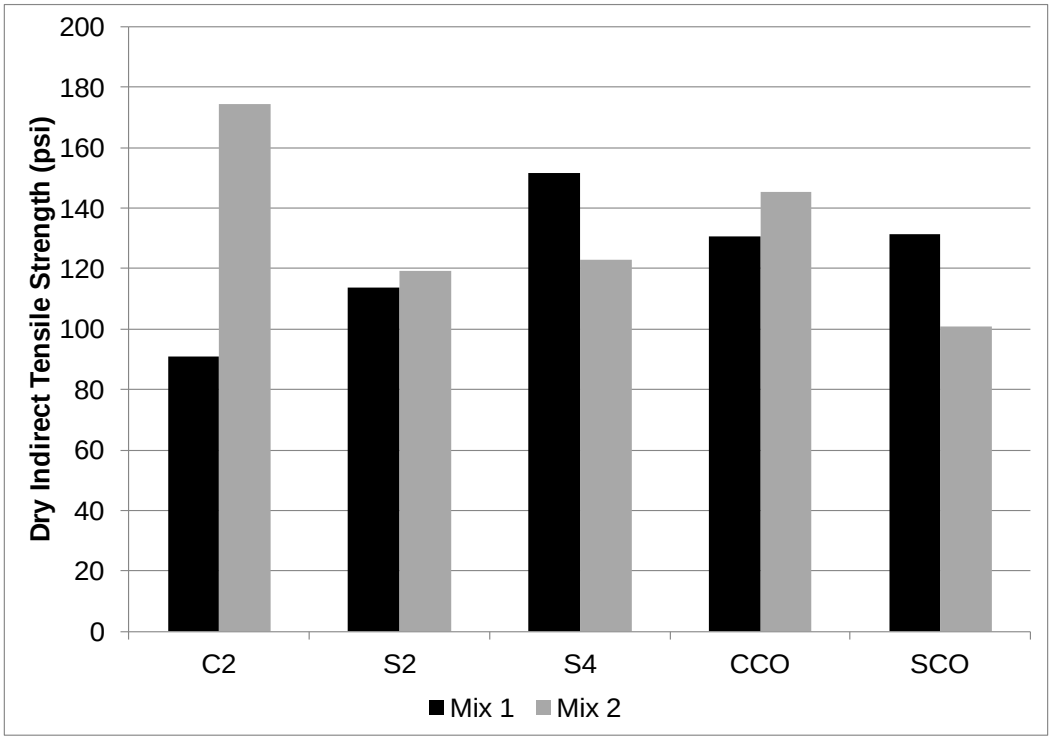

Figure 11 Effect of curing conditions on dry tensile strength, Sasobit WMA.

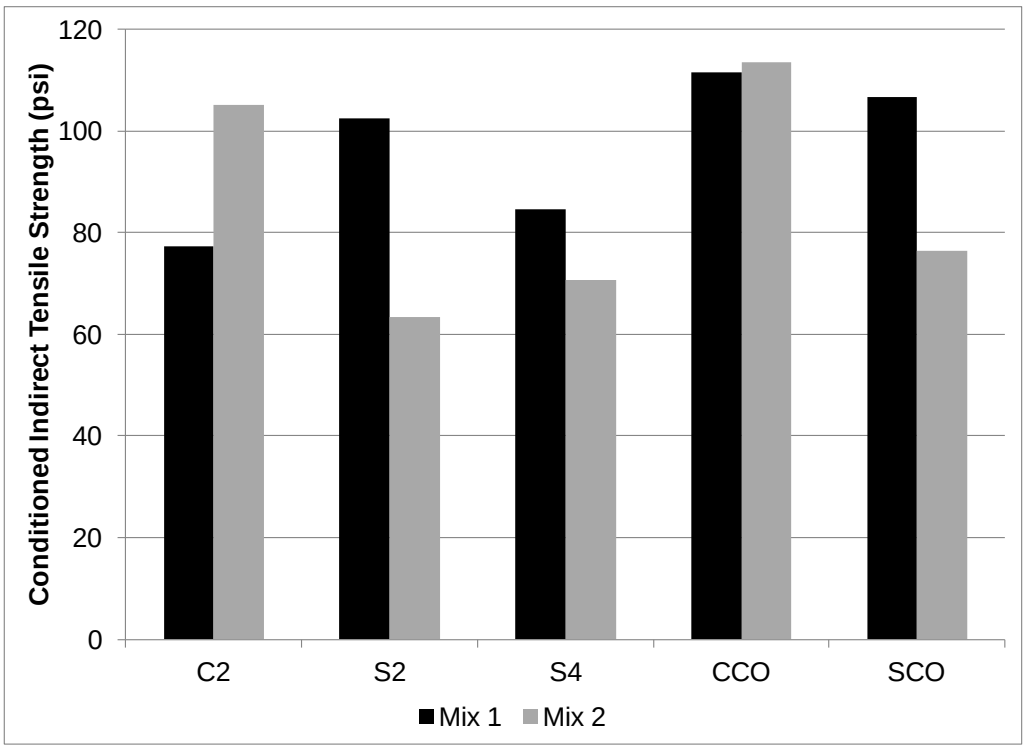

Figure 12 Effect of curing conditions on conditioned tensile strength, Sasobit WMA.

TABLE 21 Duncan's Multiple Range Test on Tensile Strength, Sasobit WMA

Mix 1				Mix 2			
Grouping	**Mean**	**N**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Dry Indirect Tensile Strength (psi)							
A	151.7	3	S4	A	174.4	3	C2
A B	131.3	3	SCO	B	145.2	3	CCO
A B	130.8	3	CCO	C	123.1	3	S4
B	113.6	3	S2	C	119.4	3	S2
C	90.8	1	C2	D	100.7	3	SCO
Conditioned Indirect Tensile Strength (psi)							
A	111.5	3	CCO	A	113.4	3	CCO
A	106.7	3	SCO	A	105.1	3	C2
A	102.4	3	S2	B	76.5	3	SCO
B	84.5	3	S4	B C	70.6	3	S4
B	77.2	1	C2	C	63.4	3	S2

For Mix 1, the control conditioned and dry tensile strengths were the lowest. For Mix 2, the control tensile strengths were the highest. The 4-hour cure samples were generally the closest lab compacted samples to the control samples. Reheating the

Sasobit samples resulted in similar results to reheated control samples for Mix 1 but not for Mix 2.

Tensile Strength Ratio

The results of the tensile strength ratio testing from AASHTO T 283 are shown in Figure 13. Replicate samples for AASHTO T 283 were not performed. Therefore, to determine if TSRs between the control mix and Sasobit WMA samples should be considered similar, the single operator acceptable range of two TSR results of 0.093, as reported by Azari, (14) was utilized. Table 22 shows the TSR for each curing condition and the difference in TSR between the control mix and each curing condition.

For Mix 1 the control, 2-hour cure and reheated samples were similar. For Mix 2 the control and 2 and 4-hour samples were similar as were the reheated samples.

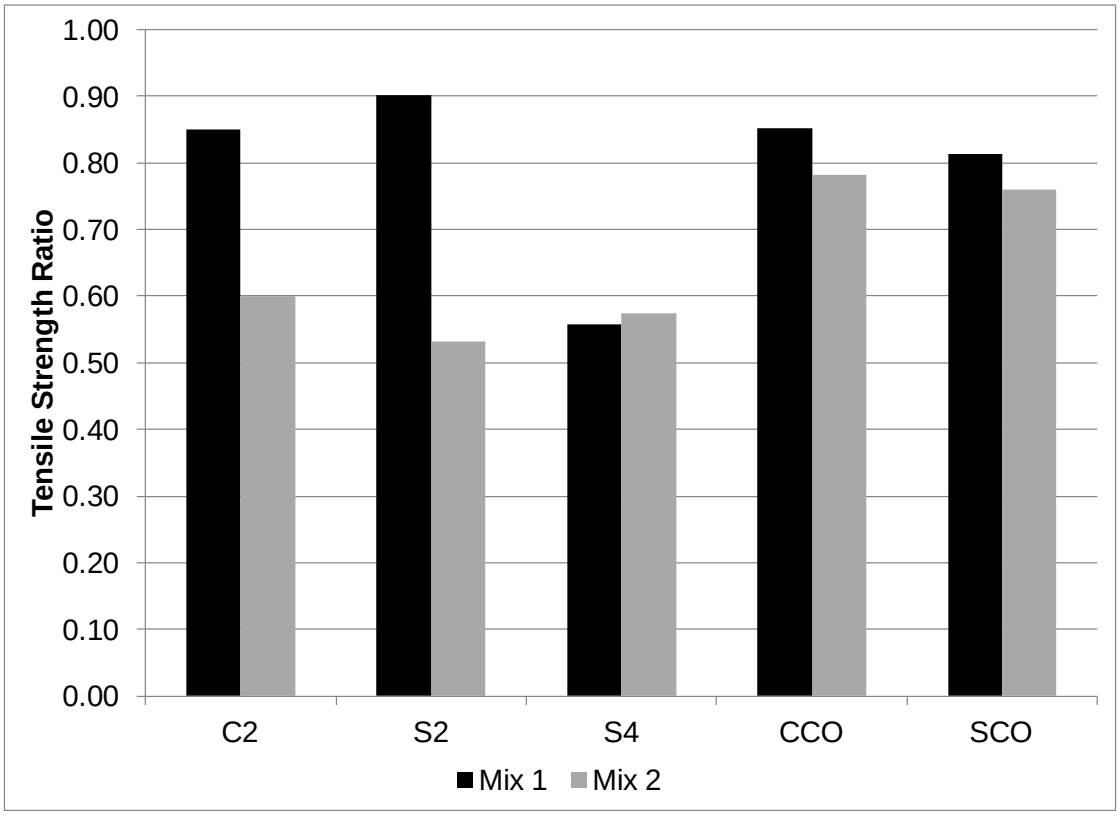

Figure 13 Effect of curing conditions on AASHTO T 283 TSR, Sasobit WMA.

TABLE 22 Summary of TSR Results, Sasobit WMA

Mix 1				Mix 2			
TSR	**Curing**	**Difference From Control**	**Similar (S) Different (D)**	**TSR**	**Curing**	**Difference From Control**	**Similar (S) Different (D)**
0.85	C2	*		0.60	C2	*	
0.90	S2	0.05	S	0.53	S2	0.07	S
0.56	S4	0.29	D	0.57	S4	0.03	S
0.81	SCO	0.04	S	0.76	SCO	-0.16	D
0.85	CCO	0.00	S	0.78	CCO	-0.18	D

Hamburg Rut Test

Results of the mean rut depths from the Hamburg Rut Test (OHD L-55) are shown in Figure 14. The ANOVA indicated a significant difference in mean rut depth for the different curing conditions, by mix, at a level of significance exceeding 95% (alpha < 0.05). Duncan's Multiple Range Test was performed to determine which means were statistically different. The results are shown in Table 23.

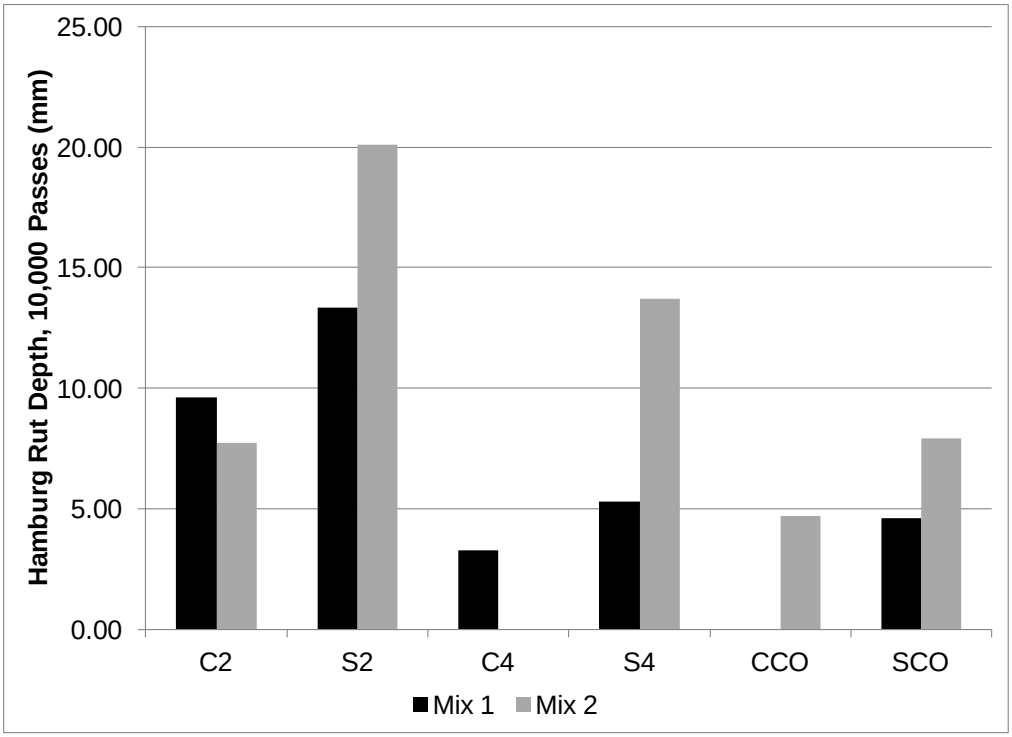

Figure 14 Effect of curing conditions on Hamburg rut depths, Sasobit WMA.

TABLE 23 Duncan's Multiple Range Test on Hamburg Rut Depths, Sasobit WMA

Mix 1				Mix 2			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Mean Rut Depth at 10,000 Passes (mm)							
A	13.35	2	S2	A	20.10	2	S2
A B	9.60	2	C2	B	13.70	2	S4
B	5.30	2	S4	C	7.90	2	SCO
B	4.60	2	SCO	C	7.75	2	C2
				D	4.70	2	CCO

For Mix 1 and 2 the 2-hour Sasobit samples rutted the most. Extending the cure time and reheating samples resulted in less rutting.

EVOTHERM

WMA samples were made with Evotherm from Mixes 1 and 2. Evotherm WMA samples were tested for laboratory produced mix properties and field simulated mix properties. Plant produced Evotherm samples were not available for these mixes. Control mixes were tested at 2 and 4 hour oven aging and after allowing the 2- hour oven aged mix to cool below 100^{o}F (overnight), reheating to 265^{o}F and compacting.

Specific Gravity

Results of the lab molded bulk specific gravity testing and maximum specific gravity testing are shown in Figures 15 and 16, respectively. To determine if the differences in mean Gmb and Gmm were statistically significant, an analysis of variance (ANOVA) was performed on the curing condition by mix type. At a level of significance of 95% ($\alpha = 0.05$) there was a significant difference in curing condition for Gmb by mix. For Gmm, there was a significant difference in means for Mix 2 but not for Mix 1. To determine which means were statistically different, Duncan's Multiple Range Test was performed. The results are shown in Table 24.

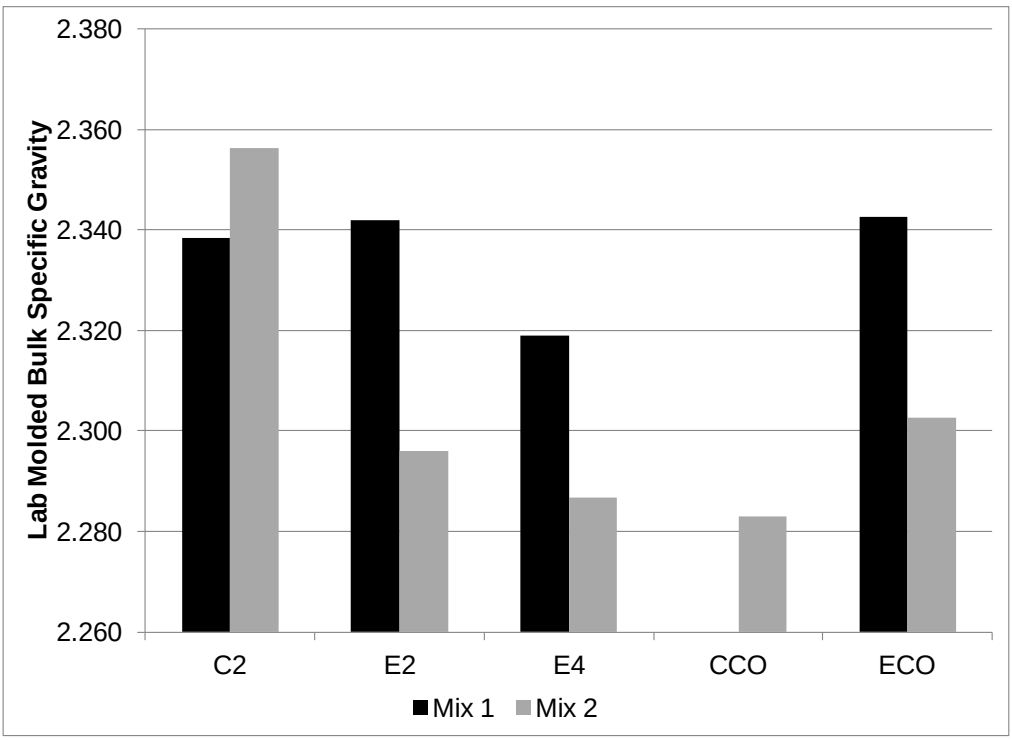

Figure 15 Effect of curing conditions on bulk specific gravity, Evotherm WMA.

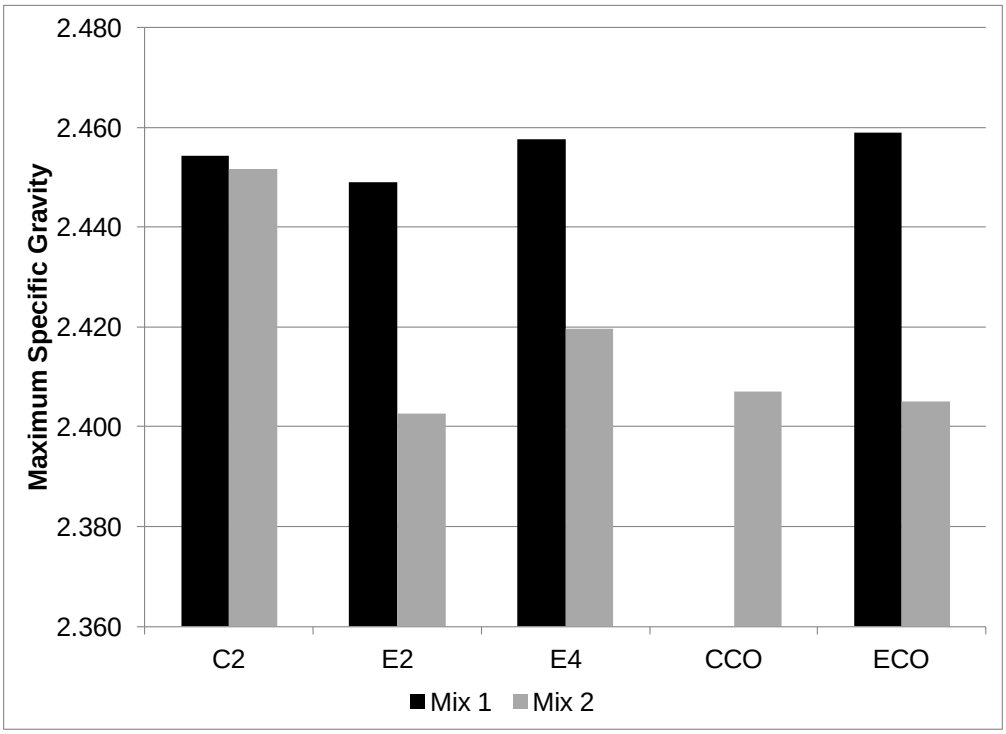

Figure 16 Effect of curing conditions on maximum specific gravity, Evotherm WMA.

TABLE 24 Duncan's Multiple Range Test on Specific Gravity, Evotherm WMA

Mix 1				Mix 2			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Gmb							
A	2.343	3	ECO	A	2.356	3	C2
A	2.342	3	E2	B	2.303	3	ECO
A	2.338	3	C2	B C	2.296	3	E2
B	2.319	3	E4	C	2.287	3	E4
				C	2.283	3	CCO
Gmm							
A	2.459	3	ECO	A	2.452	3	C2
A	2.458	3	E4	B	2.420	3	E4
A	2.454	3	C2	C	2.407	3	CCO
A	2.449	3	E2	D	2.405	3	ECO
				D	2.403	3	E2

The control and 2-hour Evotherm Gmb samples were similar for Mix 1. The 2-hour cure samples were the closest to the control mix for Mix 2. All Gmm samples were similar for Mix 1 and the 4-hour cure samples were the closest to the control mix for Mix 2.

AASHTO T 283 Testing

Tensile Strength

Results of dry and conditioned indirect tensile strength test results are shown in Figures 17 and 18, respectively. The ANOVA indicated a significant difference in tensile strengths for curing condition, by mix, at a level of significance exceeding 95% ($\alpha < 0.05$). Duncan's Multiple Range Test was used to determine which means were statistically different. The results are shown in Table 25.

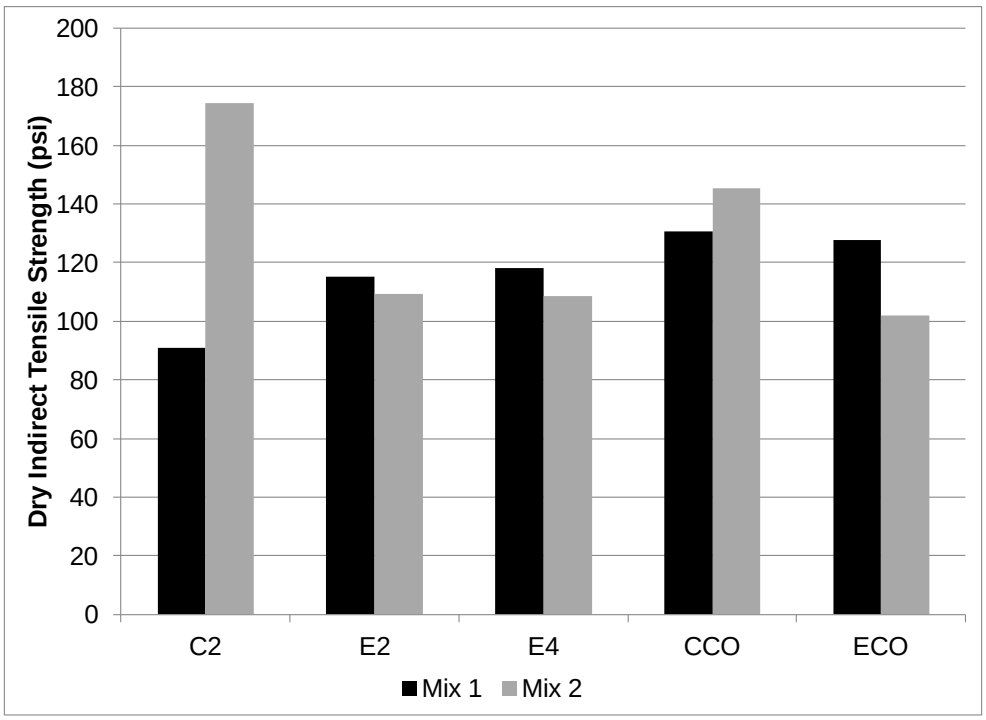

Figure 17 Effect of curing conditions on dry tensile strength, Evotherm WMA.

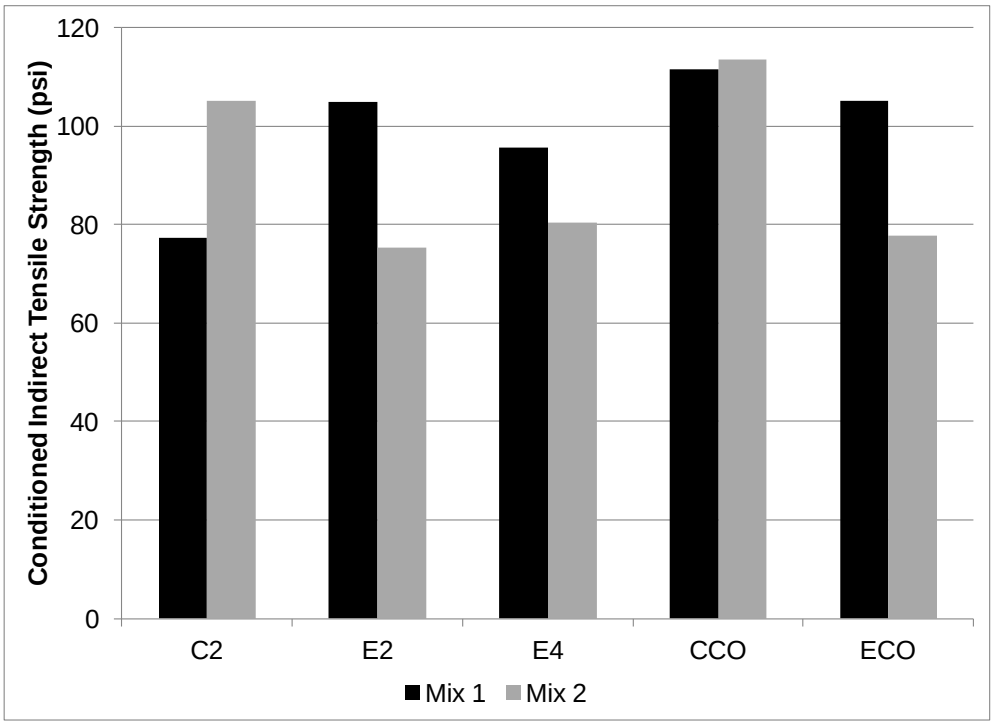

Figure 18 Effect of curing conditions on conditioned tensile strength, Evotherm WMA.

TABLE 25 Duncan's Multiple Range Test on Tensile Strength, Evotherm WMA

Mix 1				Mix 2			
Grouping	**Mean**	**N**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Dry Indirect Tensile Strength (psi)							
A	130.8	3	CCO	A	174.4	3	C2
A	127.6	3	ECO	B	145.2	3	CCO
A	118.0	3	E4	C	109.2	3	E2
A	115.1	3	E2	C	108.5	3	E4
B	90.8	1	C2	C	101.8	3	ECO
Conditioned Indirect Tensile Strength (psi)							
A	111.5	3	CCO	A	113.4	3	CCO
A B	105.1	3	ECO	A	105.1	3	C2
A B	104.9	3	E2	B	80.3	3	E4
B	95.5	3	E4	B	77.8	3	ECO
C	77.2	1	C2	B	75.4	3	E2

For Mix 1, the Evotherm samples had higher tensile strength than the control samples. Evotherm usually contains an adhesion promoter. There was no statistical difference between the 2 and 4-hour Evotherm samples. Reheating Evotherm had mixed results.

Tensile Strength Ratio

The results of the tensile strength ratio testing from AASHTO T 283 are shown in Figure 19. Replicate samples for AASHTO T 283 were not performed. Therefore, to determine if TSRs between the control mix and Evotherm WMA samples should be considered similar, the single operator acceptable range of two TSR results of 0.093, as reported by Azari, (14) was utilized. Table 26 shows the TSR for each curing condition and the difference in TSR between the control mix and each curing condition.

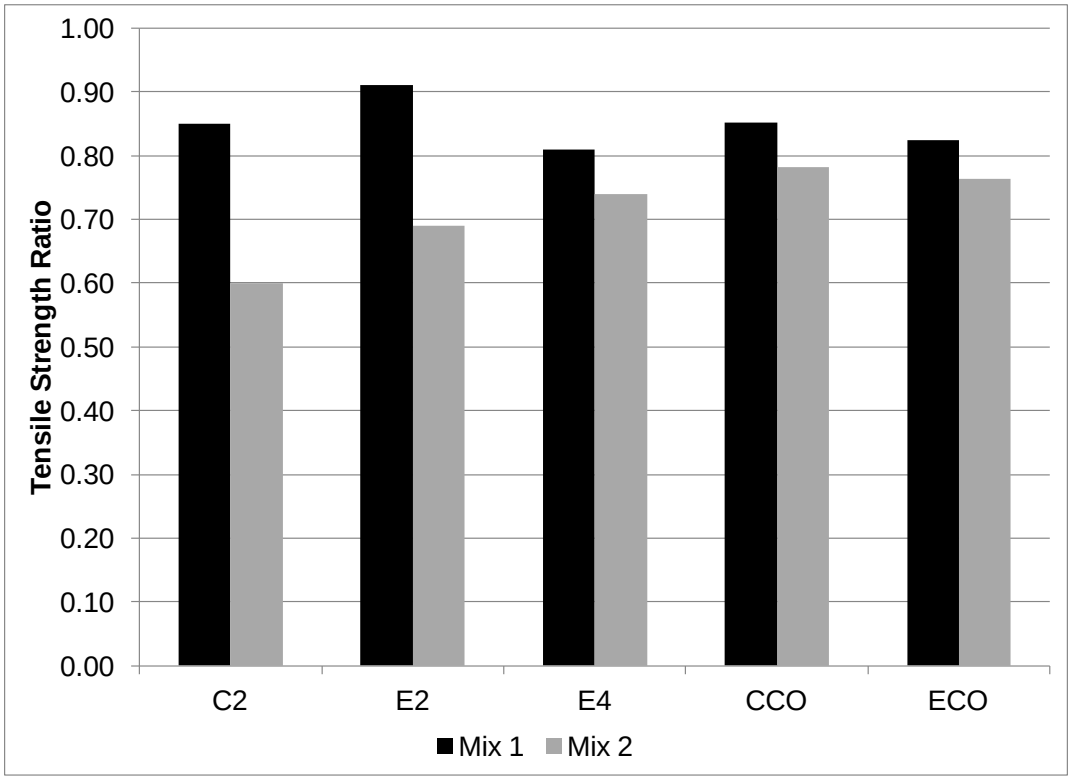

Figure 19 Effect of curing conditions on AASHTO T 283 TSR, Evotherm WMA.

TABLE 26 Summary of TSR Results, Evotherm WMA

Mix 1				Mix 2			
TSR	**Curing**	**Difference From Control**	**Similar (S) Different (D)**	**TSR**	**Curing**	**Difference From Control**	**Similar (S) Different (D)**
0.85	C2	*		0.60	C2	*	
0.91	E2	-0.06	S	0.69	E2	-0.09	S
0.81	E4	0.04	S	0.74	E4	-0.14	D
0.82	ECO	0.03	S	0.76	ECO	-0.16	D
0.85	CCO	0.00	S	0.78	CCO	-0.18	D

There was no difference in TSR values for Mix 1. For Mix 2, the 2-hour TSR was similar to the control mix and the reheated samples were similar but not equal to the control mix TSR.

Hamburg Rut Test

Results of the mean rut depths from the Hamburg Rut Test (OHD L-55) are shown in Figure 20. The ANOVA indicated a significant difference in mean rut depth for the

different curing conditions, by mix, at a level of significance exceeding 95% (alpha < 0.05). Duncan's Multiple Range Test was performed to determine which means were statistically different. The results are shown in Table 27.

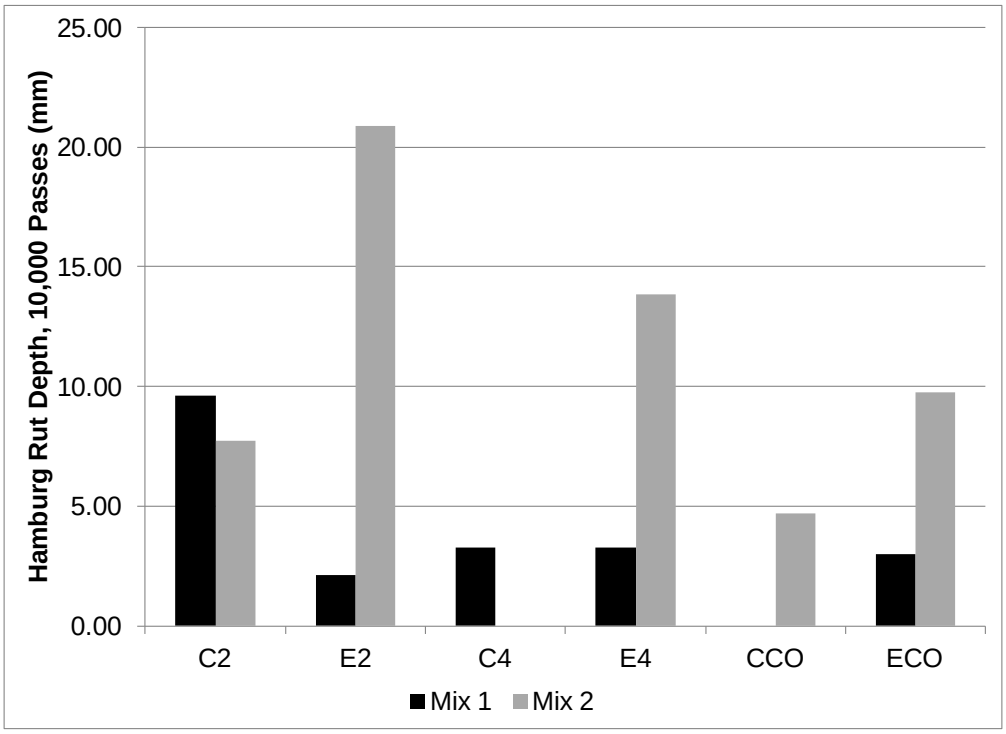

Figure 20 Effect of curing conditions on Hamburg rut depths, Evotherm WMA.

TABLE 27 Duncan's Multiple Range Test on Hamburg Rut Depths, Evotherm WMA

Mix 1				Mix 2			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Mean Rut Depth at 10,000 Passes (mm)							
A	9.60	2	C2	A	20.90	2	E2
B	3.25	2	E4	B	13.85	2	E4
B	3.00	2	ECO	B C	9.75	2	ECO
B	2.10	2	E2	B C	7.75	2	C2
				C	4.70	2	CCO

For Mix 1, the Evotherm samples were similar and rutted less than the control mix. For Mix 2, the Evotherm samples rutted more than the control samples and the reheated samples.

FINDINGS

Bulk Specific Gravity

WMA additives are compaction aids and should result in lower bulk specific gravity if compacted at the same temperature as a control mix. However, the WMA additives were compacted at a temperature selected to give the same voids. Results varied by WMA additive and by mix but were not typically statistically similar. There were no consistent trends when WMA mixes were allowed to cool below 100^{o}F and recompacted.

Maximum Specific Gravity

Maximum specific gravity was not as affected by WMA additives as bulk specific gravity. For Sasobit and Evotherm, there was no statistical difference in Gmm for Mix 1. For Mix 2, the 4-hour cure resulted in similar results to the control mix and the reheated results were similar.

Tensile Strength

It was expected that the tensile strengths for the WMA samples would be lower than the control samples due to the lower temperatures. However, this was not always true. Evotherm typically contains an adhesion promoter that resulted in larger tensile strengths for Evotherm than for the control mix for Mix 1. However, control mixes generally had higher tensile strengths with the 4-hour cure samples coming closest to the control mix samples. Reheated samples typically had similar results for Mix 1 but not Mix 2.

Tensile Strength Ratio

The control TSR was generally similar to the 2-hour WMA samples. Reheated samples were similar to each other and similar to the control mix for Mix 1 but not for Mix 2.

Hamburg Rut Depths

There was considerable scatter in Hamburg (OHD L-55) rut depths making trends difficult to identify. It was expected that WMA mixes would rut more but this was not always the case. Reheated samples generally rutted less than other samples.

CHAPTER 5
ANALYSIS OF FOAMED WMA

TEST PLAN

Foamed WMA mixes were evaluated for their effects on mix design properties and field control test properties from plant produced foamed WMA. Mix design properties included lab molded voids, maximum theoretical specific gravity, TSR and tensile strengths, and Hamburg rut depths. Field control test properties included the same tests as mix design properties. In addition, TSR and Hamburg results were evaluated to determine the effect of sample reheating on mix properties. Table 28 shows the codes used and the mix conditioning protocol used. The first letter is the material or WMA additive. The second or second and third symbol represents the aging condition.

TABLE 28 Identification Code, Foamed WMA

1st Symbol	Description	2nd Symbol(s)	Description
Laboratory Produced Samples			
C	Control	2	Heat asphalt, aggregate 325°F and mix. Oven age 2 hrs 300°F and compact
F	Foam	2	Heat asphalt 325°F, aggregate 290°F and mix. Oven age 2 hrs 265°F and compact.
		4	Heat asphalt 325°F, aggregate 290°F and mix. Oven age 4 hrs 265°F and compact.
		16	Heat asphalt 325°F, aggregate 290°F and mix. Oven age 2 hrs 265°F, compact, age compacted samples for 16 hrs at 140°F.
Plant Produced Samples			
C	Control	CO	Allow to cool below 100°F (overnight), reheat to 300°F and compact.
		R	Keep sample above 100°F, reheat to 265°F and compact same day.
F	Foam	CO	Allow sample to drop below 100°F, reheat to 265°F and compact.

SPECIFIC GRAVITY

Results of the lab molded bulk specific gravity testing and maximum specific gravity testing are shown in Figures 21 and 22, respectively. To determine if the differences in mean Gmb and Gmm were statistically significant, an analysis of variance (ANOVA)

was performed on the curing condition by mix type. There was a significant difference in curing condition for Gmb and Gmm, by mix, at a level of significance exceeding 95% ($\alpha < 0.05$). To determine which means were statistically different, Duncan's Multiple Range Test was performed. The results are shown in Table 29.

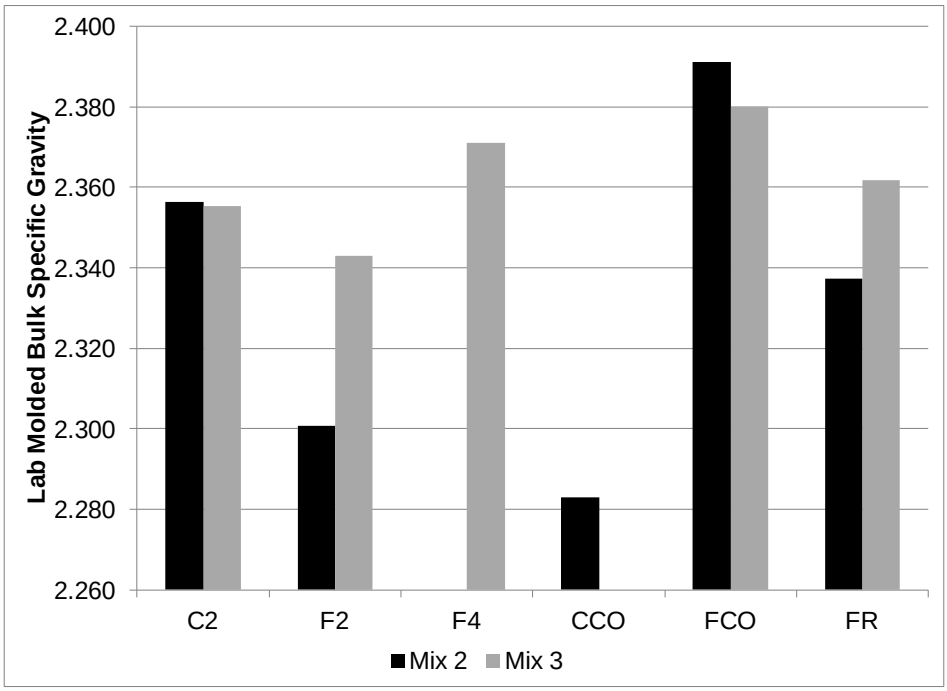

Figure 21 Effect of curing conditions on bulk specific gravity, foamed WMA.

TABLE 29 Duncan's Multiple Range Test on Specific Gravity, Foamed WMA

Mix 2				Mix 3			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Gmb							
A	2.391	3	FCO	A	2.380	3	FCO
B	2.356	3	C2	A B	2.371	3	F4
C	2.337	3	FR	B C	2.362	3	FR
D	2.301	3	F4	B C	2.355	3	C2
E	2.283	3	CCO	C	2.343	3	F2
Gmm							
A	2.452	3	C2	A	2.484	3	FCO
A B	2.442	3	FCO	A	2.481	3	FR
B	2.436	3	FR	A	2.480	3	C2
C	2.407	3	CCO	B	2.442	3	F4
C	2.403	3	F2	B	2.440	3	F2

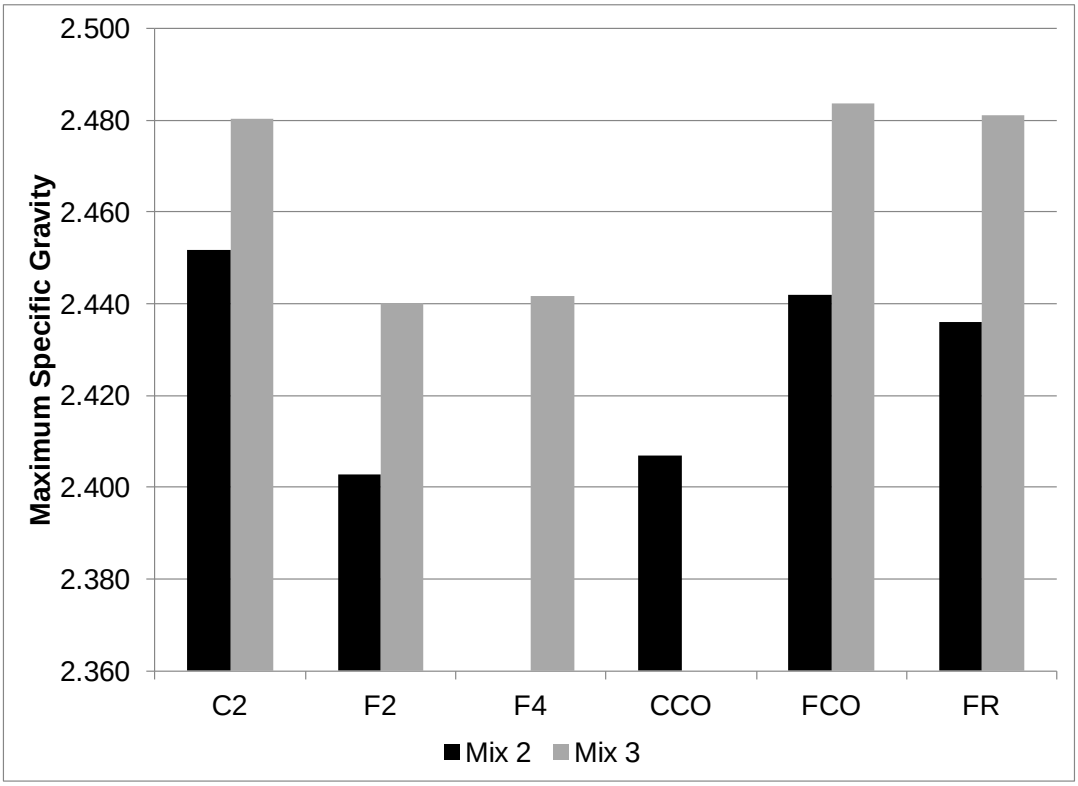

Figure 22 Effect of curing conditions on maximum specific gravity, foamed WMA.

For Mix 2, all Gmb samples were statistically different. For Mix 3, the 2 hour cure samples were similar to the control mix. For maximum specific gravity, reheating the foamed samples gave similar results to the control mixes.

AASHTO T 283 TESTING

Tensile Strength

Results of dry and conditioned indirect tensile strength test results are shown in Figures 23 and 24, respectively. The ANOVA indicated a significant difference in curing condition at a level of significance of 95% ($\alpha = 0.05$) for dry and conditioned indirect tensile strength, by mix. To determine which means were statistically different, Duncan's Multiple Range Test was performed. The results are shown in Table 30.

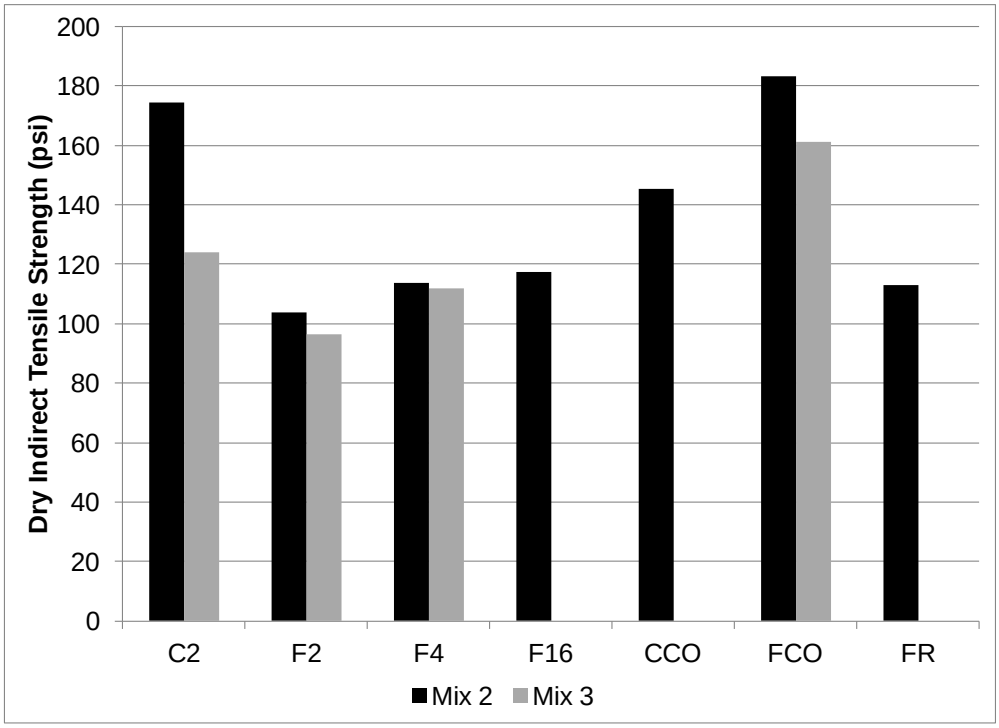

Figure 23 Effect of curing conditions on dry tensile strength, foamed WMA.

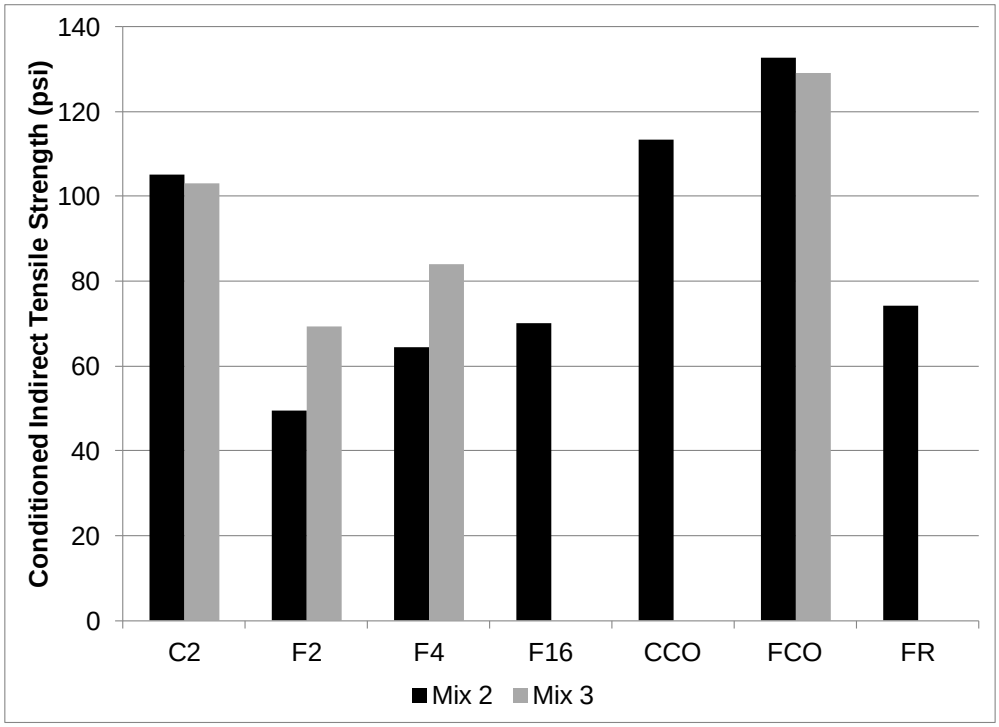

Figure 24 Effect of curing conditions on conditioned tensile strength, foamed WMA.

TABLE 30 Duncan's Multiple Range Test on Tensile Strength, Foamed WMA

Mix 2				Mix 3			
Grouping	**Mean**	**N**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Dry Indirect Tensile Strength (psi)							
A	183.3	3	FCO	A	161.0	3	FCO
A	174.4	3	C2	B	140.6	3	FR
B	145.2	3	CCO	C	124.0	3	C2
C	117.4	3	F16	C	111.8	3	F4
C	113.6	3	F4	D	96.5	3	F2
C	113.0	3	FR				
C	103.9	3	F2				
Conditioned Indirect Tensile Strength (psi)							
A	132.7	3	FCO	A	134.1	3	FR
B	113.4	3	CCO	A	129.0	3	FCO
B	105.1	3	C2	B	103.0	3	C2
C	74.1	3	FR	C	83.9	3	F4
C	70.0	3	F16	D	69.3	3	F2
C	64.5	3	F4				
D	49.4	3	F2				

Foamed tensile strength results were more consistent than the WMA additives. Control tensile strengths were consistently larger than foamed samples. The longer foamed samples were aged the higher the tensile strengths. Reheating samples resulted in larger tensile strengths. However, there was no consistent trend for foamed curing conditions being similar to control mix samples.

Tensile Strength Ratio

The results of the TSR testing from AASHTO T 283 are shown in Figure 25. Replicate samples for AASHTO T 283 were not performed. The single operator acceptable range of two TSR results of 0.093, as reported by Azari, (14) was utilized to determine if TSRs between the control mix and foamed WMA samples should be considered similar. Table 31 shows the TSR for each curing condition and the difference in TSR between the control mix and each curing condition.

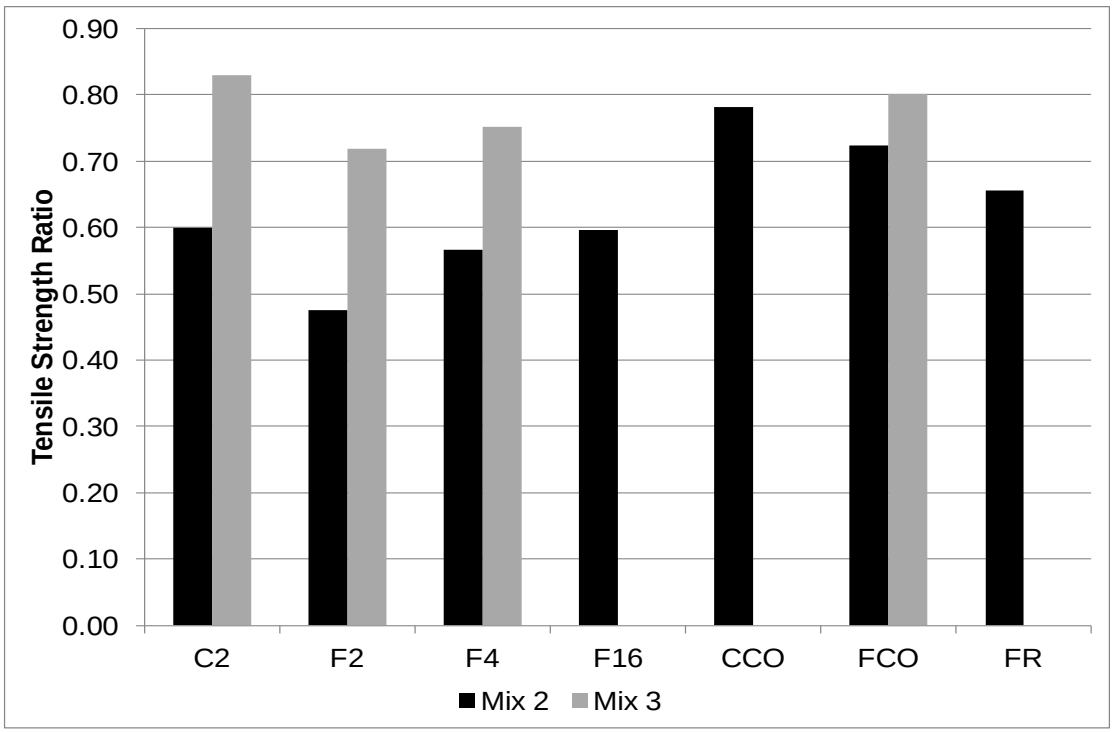

Figure 25 Effect of curing conditions on AASHTO T 283 TSR, foamed WMA.

TABLE 31 Summary of TSR Results, Foamed WMA

Mix 2				Mix 3			
TSR	**Curing**	**Difference From Control**	**Similar (S) Different (D)**	**TSR**	**Curing**	**Difference From Control**	**Similar (S) Different (D)**
0.60	C2	*		0.83	C2	*	
0.48	F2	0.12	D	0.72	F2	0.11	D
0.57	F4	0.03	S	0.75	F4	0.08	S
0.60	F16	0.00	S	*	*	*	*
0.66	FR	-0.06	S	0.95	FR	-0.12	D
0.72	FCO	-0.12	D	0.80	FCO	0.03	S
0.78	CCO	-0.18	D				

For both Mix 2 and 3, the 4-hour cured foamed samples were similar to the control mix samples. Reheated results varied by mix.

HAMBURG RUT TEST

Results of the mean rut depths from the Hamburg (OHD L-55) Rut Test are shown in Figure 26. The ANOVA indicated a significant difference in mean rut depth for the

different curing conditions, by mix, at a level of significance exceeding 95% (alpha < 0.05). Duncan's Multiple Range Test was performed to determine which means were statistically different. The results are shown in Table 32.

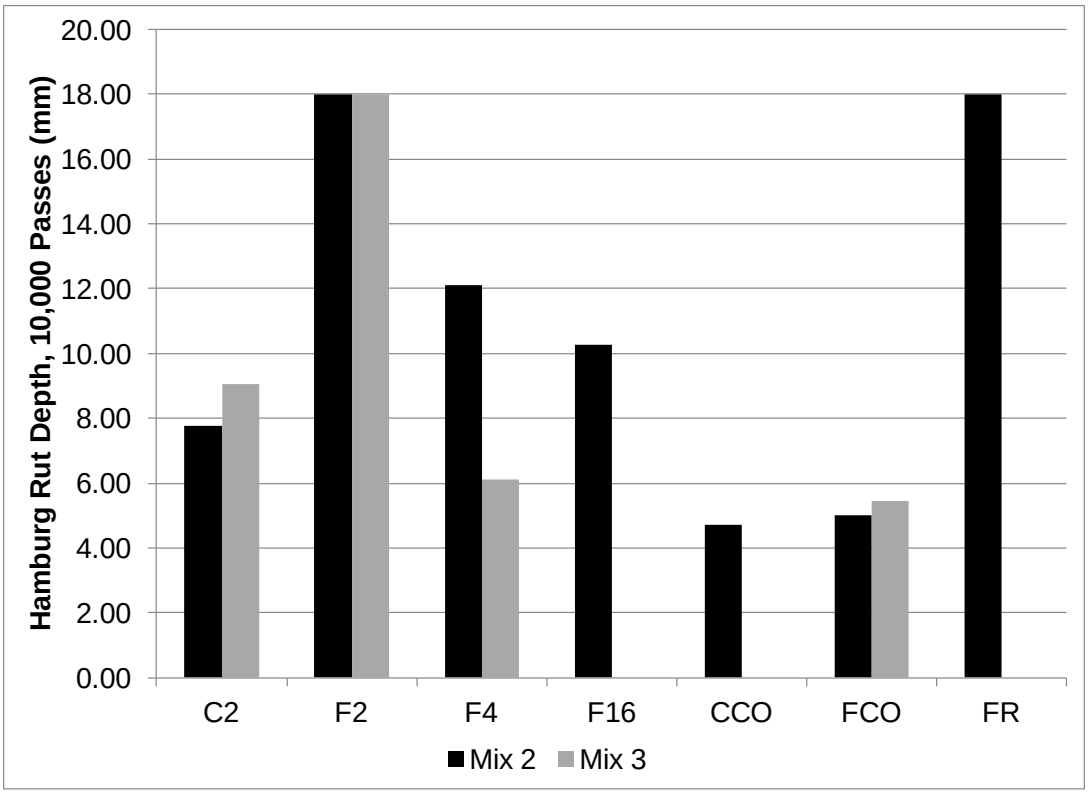

Figure 26 Effect of curing conditions on Hamburg rut depths, foamed WMA.

TABLE 32 Duncan's Multiple Range Test on Hamburg Rut Depths, Foamed WMA

Mix 2				Mix 3			
Grouping	**Mean**	**n**	**Curing**	**Grouping**	**Mean**	**n**	**Curing**
Mean Rut Depth at 10,000 Passes (mm)							
A	18.00+	2	FR	A	18.00+	2	F2
A	18.00+	2	F2	A B	12.35	2	FR
B	12.10	2	F4	B	9.05	2	C2
B C	10.25	2	F16	B	6.10	2	F4
C D	7.75	2	C2	B	5.45	2	FCO
D E	5.00	2	FCO				
E	4.70	2	CCO				

Mix 2 foamed samples rutted more than the control mix sample. Reheated samples had the lowest rut depths. For Mix 3, the control and 4-hour cure foamed samples had similar rut depths. The 2-hour cure and reheated (R) samples failed the Hamburg test. The longer foamed samples were aged the less rutting.

FINDINGS

Bulk Specific Gravity

Foamed WMA is a compaction aid and should result in lower bulk specific gravity if compacted at the same temperature as a control mix. When compacting at a lower temperature results varied by mix. For Mix 2, all Gmb samples were statistically different. For Mix 3, the 2-hour cure sample was similar to the control mix.

Maximum Specific Gravity

Maximum specific gravity was not as affected by the foamed WMA additive as bulk specific gravity. For Mix 3, the 4-hour cure sample was closest to the control mix. Reheating foamed samples gave similar results to control mixes.

Tensile Strength

It was expected that tensile strengths for the WMA samples would be lower than the control samples due to the lower temperatures and this was true. Foamed tensile strength results were more consistent than the WMA additives. Control mix tensile strengths were consistently larger than foamed samples. The longer foamed samples were aged the higher the tensile strengths. Reheating samples resulted in larger tensile strengths. However, there was no consistent trend of foamed curing conditions being similar to control.

Tensile Strength Ratio

The control TSR was generally similar to the 4-hour foamed WMA samples. Reheated samples varied by mix.

Hamburg Rut Depths

There was considerable scatter in Hamburg (OHD L-55) rut depths making trends difficult to identify. It was expected that foamed mixes would rut more but this was not always the case. The longer foamed samples were aged the less rutting. Reheated samples had the lowest rut depths.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

There was considerable scatter in the test data. This could be the result of normal variability of the test methods and possible unfamiliarity of working with the WMA technologies. This scatter in test results would require that a considerable number of samples and mixes be made before definitive conclusions and recommendations could be made. Based on the limited data, the following conclusions for mix design testing and field quality assurance testing are made.

Laboratory Mix Designs

WMA technologies are a compaction aid and the reduced temperatures have an effect on binder oxidation rates and mix stiffness. How samples are handled during mix design will affect test results.

There are two procedures that could be followed for mix designs. The first possibility would be to perform a normal mix design in accordance with AASHTO R 35 without using the WMA technology (additive of foam). This would be required for foamed WMA if a laboratory foamer was not available. TSR results were found to be generally similar for WMA and control mixes but Hamburg (OHD L-55) rut depths were not similar. The literature confirmed this finding (4). WMA mixes have not been prone to rutting in the field (15); therefore, performing AASHTO T 283 and OHD L-55 on the control mix only would be feasible procedures.

If desired, AASHTO T 283 and OHD L-55 testing could be performed on samples made with the WMA additive or foam (if a foamer is available). Samples should be made at the JMF asphalt content with the desired WMA technology. Samples should be compacted after a 4-hour oven aging at the reduced compaction temperature selected by the contractor. TSR values should be similar but tensile strength results could be lower than a control mix. OHD L-55 rut depths would probably be higher than a control mix, making this procedure possibly conservative.

A second procedure would be to perform the mix design with the WMA technology. A laboratory foamer would be required for foamed WMA. Samples should be compacted after a 4-hour oven aging at the reduced compaction temperature selected by the contractor. TSR values should be similar but tensile strength results could be lower than a control mix. OHD L-55 rut depths would probably be higher than a control mix, making this procedure possibly conservative.

Quality Assurance Testing

How long a specific WMA technology affects a mix's workability is a function of the specific WMA technology. Allowing an Advera WMA mix to cool to ambient temperatures is reported to negate the compaction aiding effects (11). Mixed results were observed with Advera as well as with the other WMA technologies. However, it did appear that allowing samples to cool below 100^{o}F before reheating to the compaction temperature resulted in results more similar to control mix properties than keeping samples warm, reheating and compacting at the compaction temperature. Tensile strengths still tended to be lower than control mixes and OHD L-55 rut depths were slightly higher.

RECOMMENDATIONS

As previously stated, there was considerable scatter in the data. This scatter in test results would require a considerable number of samples and mixes be made before definitive recommendations could be made. Based on the limited data, the following recommendations for mix design testing and field quality assurance testing are made. If these recommendations are adopted, the mix design and QA procedures should be verified and adjusted as additional data warrants.

Laboratory Mix Designs

Perform WMA mix designs in accordance with AASHTO R 35 using the desired WMA technology. Mix design samples should be compacted after a 4-hour oven aging at the reduced compaction temperature selected by the contractor. Mixing should be performed at a temperature 25^{o}F higher than the selected compaction temperature. Binder should be heated to 325^{o}F for mixing. Performance test samples (AASHTO T

283 and OHD L-55) should be made in the same way as mix design samples but compacted to the specified thickness and air void content. TSR values should be similar but tensile strength results could be lower than a control mix. OHD L-55 rut depths would probably be higher than a control mix, making this procedure possibly conservative.

If a laboratory foamer is not available, perform a mix design for foamed WMA mixes in accordance with AASHTO R 35. Plant produced mixes would be required to evaluate AASHTO T 283 and OHD L-55. Sample plant produced mix and allow the mix to cool below 100^{o}F. After the mix drops below 100^{o}F, reheat the mix to the compaction temperature and compact samples to the desired thickness and void content for AASHTO T 283 and OHD L-55 testing.

Quality Assurance Testing

For quality assurance testing, plant produced mix should be sampled and allowed to cool below 100^{o}F before testing. After the mix has cooled below 100^{o}F, the mix should be brought back up to the compaction temperature. Compaction samples should then be immediately compacted to the desired number of gyrations in the SGC or to the desired thickness and void content, depending upon the QA test. Samples for maximum specific gravity should be allowed to cool below 100^{o}F and reheated to the compaction temperature. As soon as the mix reaches the desired compaction temperature it should be allowed to cool to test temperature in accordance with AASHTO T 209.

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