Potential Use and Applications for Reclaimed Millings

Morgan State University
The Pennsylvania State University
University of Maryland
University of Virginia
Virginia Polytechnic Institute & State University
West Virginia University

The Pennsylvania State University
The Thomas D. Larson Pennsylvania Transportation Institute
Transportation Research Building ❖ University Park, PA 16802-4710
Phone: 814-865-1891 ❖ Fax: 814-863-3707
www.mautc.psu.edu

pennsylvania
DEPARTMENT OF TRANSPORTATION

Potential Use and Applications for Reclaimed Millings

Task 5.2: Report of Findings and Recommendations for Other Applications

January 15, 2015
Revised June 11, 2015

By Shelley M. Stoffels, Mansour Solaimanian and Saman Barzegari

The Thomas D. Larson
Pennsylvania Transportation Institute

PENNSTATE
1855

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

CONTRACT # 4400008014
WORK ORDER # PSU 004

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-PA-2014-009-PSU WO 4		

4. Title and Subtitle	5. Report Date
Potential Use and Applications for Reclaimed Millings: Report of Findings and Recommendations for Other Applications for Reclaimed Millings	June 11, 2015
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Shelley Stoffels, Mansour Solaimanian, and Saman Barzegari	LTI 2015-15

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Thomas D. Larson Pennsylvania Transportation Institute The Pennsylvania State University 201 Transportation Research Building University Park PA 16802	**11. Contract or Grant No.** **4400008014, PSU WO 4**

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Pennsylvania Department of Transportation Bureau of Planning and Research Commonwealth Keystone Building 400 North Street, 6th Floor Harrisburg, PA 17120-0064 US Department of Transportation Research & Innovative Technology Administration UTC Program, RDT-30 1200 New Jersey Ave., SE Washington, DC 20590	Task 5.2 Report: 5/1/2013 – 1/15/2015
	14. Sponsoring Agency Code

15. Supplementary Notes

Douglas Schofield (dschofield@pa.gov), Maintenance Services Engineer, Engineering District 1-0, Pennsylvania Department of Transportation, served as the technical advisor on this project. Heather Heslop (hheslop@pa.gov) was the research project manager.

16. Abstract

The purpose of this project was to provide support to PennDOT District 1-0 in the effective use of milled asphalt material. Specifically, District 1-0 has a shortage of high-quality available coarse aggregate and has developed the innovative procedure of breaking down and sorting recycled asphalt pavement (RAP) to recover the older high-quality aggregate for use on higher-volume roadways. The focus of this project was on the usage of the remaining asphalt and fines. This report documents Task 5. The objective of Task 5 was the laboratory exploration of two promising applications for the reclaimed fine millings. The two applications investigated were use of the reclaimed millings in thin cold-mix overlays, and the possibility of using a cold mix of the reclaimed millings with virgin-grade C aggregates to replace the scalped #8 aggregates for binder course or low-volume secondary roads.

17. Key Words	18. Distribution Statement
Reclaimed millings, recycled asphalt pavement (RAP), fractionated RAP, cold mix asphalt	No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	47	NA

This work was sponsored by the Pennsylvania Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the Federal Highway Administration, U.S. Department of Transportation, or the Commonwealth of Pennsylvania at the time of publication. This report does not constitute a standard, specification, or regulation.

Table of Contents

List of Tables

List of Figures

Project Overview

The overall objective of the Work Order 4 project was to provide support to PennDOT District 1-5 in the effective use of milled asphalt material. Specifically, District 1-5 has a shortage of high-quality available coarse aggregate, and has developed the innovative procedure of breaking down and sorting Recycled Asphalt Pavement (RAP) to recover the older high-quality aggregate for use on higher-volume roadways. In effect, the District is producing a type of fractionated RAP as a byproduct of the removal of the high-quality coarse aggregate.

The focus of this project was on the usage of the remaining asphalt and fines, either separately or in conjunction with the use of the coarse aggregate. The Task 1 report provided a review of the current state of the practice from literature and other available resources. Task 2 provided laboratory physical characterization (binder content and gradation) of the reclaimed millings from stockpile sampling. Task 3 provided potential applications of the reclaimed millings for a trial project. Task 4, the monitoring of the construction and performance of the trial project, has been deferred to a later time and project.

Overview of Task 5

The objective of Task 5 is to explore two promising applications for the reclaimed fine millings. Initially, in the project proposal, Task 5 was envisioned as occurring after completion of the field trial, principally to accommodate the needed timing for field construction. However, it was decided that since Task 5 includes principally laboratory characterization, it could be fulfilled before the field trial. The two applications investigated were use of the reclaimed millings in thin cold-mix overlays (Option A), and the possibility of using a cold mix of the reclaimed millings with virgin-grade C aggregates to replace the scalped #8 aggregates for binder course or low-volume secondary roads (Option B).

Table 1 summarizes the list of standards utilized during the laboratory investigations for Task 5.2.

Table 1 Test Methods for Task 5.2

Test Method	Standard
Compaction of Asphalt Specimens using SuperPave Gyratory Compactor	AASHTO T 312 ASTM D6925 - 09
Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures	ASTM D6931 - 12
Standard Test Method for Raveling Test of Cold Mixed Emulsified Asphalt Samples	ASTM 7196-12

Option A – Cold Mix Thin Overlay

To develop a cold mix suitable for a thin overlay field trial, a series of tests using one source of reclaimed millings and one emulsion CSS-1H (Appendix A) was conducted. The binder residue in the reclaimed millings was graded in Task 2. The cold mix has been developed to optimize strength and density. A series of specimens were prepared and compacted at a range of varying emulsion and water contents. Specimens were produced at two different heights: 19 mm (0.75 in) and 37.5 mm (1.5 in). Table 2 summarizes the mix proportions for the test specimens. For each specimen, density was determined, followed by indirect tensile strength testing.

Mix Design and Proportioning

A set of preliminary tests were conducted to determine the amount of reclaimed aggregates needed for each specimen height. Table 3 summarizes the amount of reclaimed aggregate required for each height.

In order to determine the number of required replicates for each mix, an initial batch consisting of four sets of proportions was selected, and for each set two replicates were prepared and compacted to the height of 19 mm (a total of eight specimens). The specimens were tested for indirect tensile strength. Table 4 summarizes the mix design and results for this initial batch.

Based on the results presented in Table 4, it was decided to continue the work with two replicates for each proportion. In total, 36 specimens were prepared.

Table 2 Summary of Mix Design for Option A

Height (mm)	Water (%)	Emulsion (%)
19	1	2.0
		2.5
		3.0
	2	2.0
		2.5
		3.0
	3	2.0
		2.5
		3.0
37.5	1	2.0
		2.5
		3.0
	2	2.0
		2.5
		3.0
	3	2.0
		2.5
		3.0

Table 3 Required Reclaimed Millings for Different Specimen Heights

Specimen Height	Required Reclaimed Aggregates (g)
19 mm (3/4")	670
37.5 mm (1.5")	1340

Table 4 Summary of Batch 1 Results for Determination of Number of Required Replicates

Water (%)	Emulsion (%)	IDT Strength (kPa)	Bulk Specific Gravity	Gmm_e	Mean IDT (kPa)	σ_{IDT} (kPa)
1	2	276.21	2.031	2.377	288.061	11.855
		299.92	2.004			
1	3	285.25	2.036	2.346	306.701	21.455
		328.16	2.031			
2	2	323.58	2.030	2.377	311.848	11.735
		300.11	2.027			
2	3	453.16	2.037	2.346	454.438	1.273
		455.71	2.031			

Reclaimed Aggregate Gradation

The reclaimed aggregate was from the same material used for Task 2. Before gradation could be determined, half of the material from the first bucket was spread and air dried. After sieve analysis of black rock, tests of extractions and ignition burn were performed. Gradation results before binder extraction for the bucket #1 sample are shown in Table 5.

Table 5 RAP Sample from Bucket #1 - Black Rock Gradation before Extraction

Sieve		Retained (g)	% Retained	Cumulative Retaining	Cumulative % Retained	% Passing
2"	50.0mm	0	0	0	0	100
1 1/2"	37.5mm	0	0	0	0	100
1"	25mm	0	0	0	0	100
3/4"	19mm	0	0	0	0	100
1/2"	12.5mm	10	0.6	10	0.6	99.4
3/8"	9.5mm	28.1	1.6	38.1	2.2	97.8
#4	4.75mm	318	17.9	356.1	20.1	79.9
#8	2.36mm	590.1	33.3	946.2	53.4	46.6
#16	1.18mm	376.5	21.3	1322.7	74.7	25.3
#30	0.6mm	242.7	13.7	1565.4	88.4	11.6
#50	0.3mm	134.7	7.6	1700.1	96	4
#100	0.15mm	39.1	2.2	1739.2	98.2	1.8
#200	0.075mm	15	0.8	1754.2	99	1
	Pan	17.5	1	1771.7	100	

Sample Preparation and Curing

The protocol provided for Work Order 3 at Penn State was followed for this test (Solaimanian, Appendix B).

The reclaimed aggregates were air-dried for 24 hours. A moisture content test was performed on the air-dried material and the moisture content was determined as 0.08%, which indicated that air-drying the material in the lab removed nearly all of the moisture. The CSS-1H emulsion asphalt was heated in a 60 ℃ oven for 60 minutes prior to mixing. The reclaimed aggregates were batched and weighed carefully, and were mixed manually with the required amount of water for 90 seconds prior to adding the emulsion. After adding the emulsion, the mixing was

continued for at least 90 seconds to ensure the complete blending of reclaimed aggregates, water, and emulsion. The mix was then moved to the environmental chamber and was allowed to set for 30 minutes at 42 ℃ before compaction. See Figures 1 and 2.

Figure 1 Mixing of reclaimed aggregates, water and emulsion for preparing the specimens

Figure 2 Mixed samples in the environmental chamber

Specimens were compacted using the SuperPave gyratory compactor following AASHTO T 312. As the thicknesses of the specimens were below the minimum achievable thickness of the compactor, a disk of compacted hot-mix asphalt concrete was used as spacer to facilitate the

preparation of specimens. Following compaction, each specimen was labeled, moved back to the environmental chamber, and cured for an additional 72 hours at 42 ℃.

Determination of Bulk and Maximum Specific Gravity of Specimens

After the 72-hour curing period in the 42 ℃ environmental chamber, the compacted specimens were placed back at ambient temperature for 2 hours. Bulk specific gravity (G_{mb}) for each of the specimens was then measured, using the CoreLok® device (Figure 3), before performing the strength tests.

Figure 3 Measurement of G_{mb} of specimens using the CoreLok® device

The maximum theoretical specific gravity of the mix with emulsion (Gmm_e) was calculated using Equation (1).

$$Gmm_e = \frac{Gmm(1+p)}{1+\frac{pGmm}{G_b}} \quad (1)$$

Where Gmm_e represents the maximum theoretical specific gravity of the mix with emulsion, Gmm represents the maximum theoretical specific gravity of the mix without emulsion, p is the percent of emulsion in the mix (by mass of mix), and G_b is the specific gravity of emulsion binder (From Appendix A).

Determination of Indirect Tensile Strength (IDT) of Specimens

The tensile strengths of the specimens were measured according to ASTM D6931–12. Table 6 summarizes the test results for the 19-mm specimens, while Table 7 presents the test results for the 37.5-mm specimens.

Based on Table 6 and Table 7, the highest tensile strength has been achieved in specimens W4-1-6 for 19-mm specimens, while in the case of the 37.5-mm specimens, the IDT of W4-2-5 specimens were slightly higher, but as the IDT of W4-1-5 were significantly lower than the W4-1-6 specimens, the desirable water content was considered as 2%, while the desirable emulsion content was selected as 3%. The highest variability was observed with the 3% emulsion. However, for most of the tests, the results of the two replicates are reasonably close, indicating consistent material preparation and testing. Appendix C includes the results of the IDT testing on all specimens for Option A.

Table 6 Summary of Test Results for Specimens with 19-mm Thickness

Water (%)	Emulsion (%)	ID	IDT Strength (kPa)	Bulk Specific Gravity (G_{mb})	Gmm_e	Air Voids (%)
1	2	W4-1-11	276.21	2.031	2.377	14.5
		W4-1-12	299.92	2.004	2.377	15.7
	2.5	W4-1-21	324.79	2.025	2.361	14.2
		W4-1-22	327.56	2.020	2.361	14.4
	3	W4-2-31	285.25	2.036	2.346	13.2
		W4-2-32	328.16	2.031	2.346	13.4
2	2	W4-1-41	323.58	2.030	2.377	14.6
		W4-1-42	300.11	2.027	2.377	14.7
	2.5	W4-1-51	295.44	2.005	2.361	15.1
		W4-1-52	280.14	2.017	2.361	14.6
	3	W4-1-61	453.16	2.037	2.346	13.2
		W4-1-62	455.71	2.031	2.346	13.4
3	2	W4-1-71	358.22	2.005	2.377	15.6
		W4-1-72	347.64	1.994	2.377	16.1
	2.5	W4-1-81	334.06	1.998	2.361	15.4
		W4-1-82	349.50	2.002	2.361	15.2
	3	W4-1-91	336.69	2.005	2.346	14.5
		W4-1-92	343.96	1.982	2.346	15.5

Table 7 Summary of Test Results for Specimens with 37.5-mm Thickness

Water (%)	Emulsion (%)	ID	IDT Strength (kPa)	Bulk Specific Gravity (G_{mb})	Gmm_e	Air Voids (%)
1	2	W4-2-11	212.39	2.032	2.377	14.5
		W4-2-12	279.93	2.019	2.377	15.1
	2.5	W4-2-21	368.38	2.044	2.361	13.4
		W4-2-22	358.96	2.042	2.361	13.5
	3	W4-2-31	371.37	2.031	2.346	13.4
		W4-2-32	389.41	2.047	2.346	12.7
2	2	W4-2-41	432.46	2.036	2.377	14.4
		W4-2-42	418.15	2.020	2.377	15.0
	2.5	W4-2-51	431.41	2.033	2.361	13.9
		W4-2-52	442.62	2.035	2.361	13.8
	3	W4-2-61	448.30	2.042	2.346	13.0
		W4-2-62	407.75	2.047	2.346	12.7
3	2	W4-2-71	404.79	2.020	2.377	15.0
		W4-2-72	363.68	2.023	2.377	14.9
	2.5	W4-2-81	426.52	2.030	2.361	14.0
		W4-2-82	430.97	2.017	2.361	14.6
	3	W4-2-91	457.62	2.035	2.346	13.3
		W4-2-92	415.57	2.001	2.346	14.7

Raveling Test

Durability of cold mixes is always of great concern in any application. While strength is an important indicator, it is not a reliable measurement of how well the mix will last once exposed to traffic loading and harsh conditions. Mixes that are not adequately durable will ravel prematurely. One of the tests proposed to evaluate durability and raveling potential of cold mixes is known as the raveling test. This test was performed to evaluate the resistance of the specimens against raveling.

For this purpose, three specimens with established mix proportions were prepared following the procedure previously described. Table 8 summarizes the properties of the specimens prepared for the raveling testing. The prepared specimens were tested for air content prior to testing for raveling. The raveling test was conducted following ASTM 7196-12. Figure 4 illustrates the instrument, while Figure 5 shows a specimen before and after running the test. The procedure of

testing for raveling consists of measuring the initial weight of the specimen, running the raveling test for 15 minutes, and calculating the mass loss due to raveling. Table 9 includes the results of the testing for raveling. Based on the observation that the mass loss due to raveling is very small, the samples that were prepared using this procedure for preparation and curing are showing good resistance to raveling.

Table 8 Mix Proportion of Specimens for Raveling Test

	Water	Emulsion	Height (mm)	Diameter (mm)
W4-R-1	2	3	65	150
W4-R-2				
W4-R-3				

Table 9 Summary of the Results of Raveling Test

	Initial Weight (g)	Final Weight (g)	Weight Loss (%)
W4-M-1	2411.5	2410	0.062
W4-M-2	2407.7	2406.4	0.054
W4-M-3	2415.2	2414.7	0.021

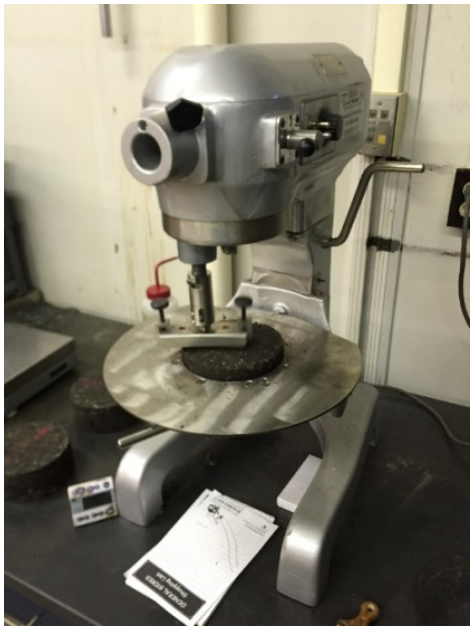

Figure 4 Raveling test equipment

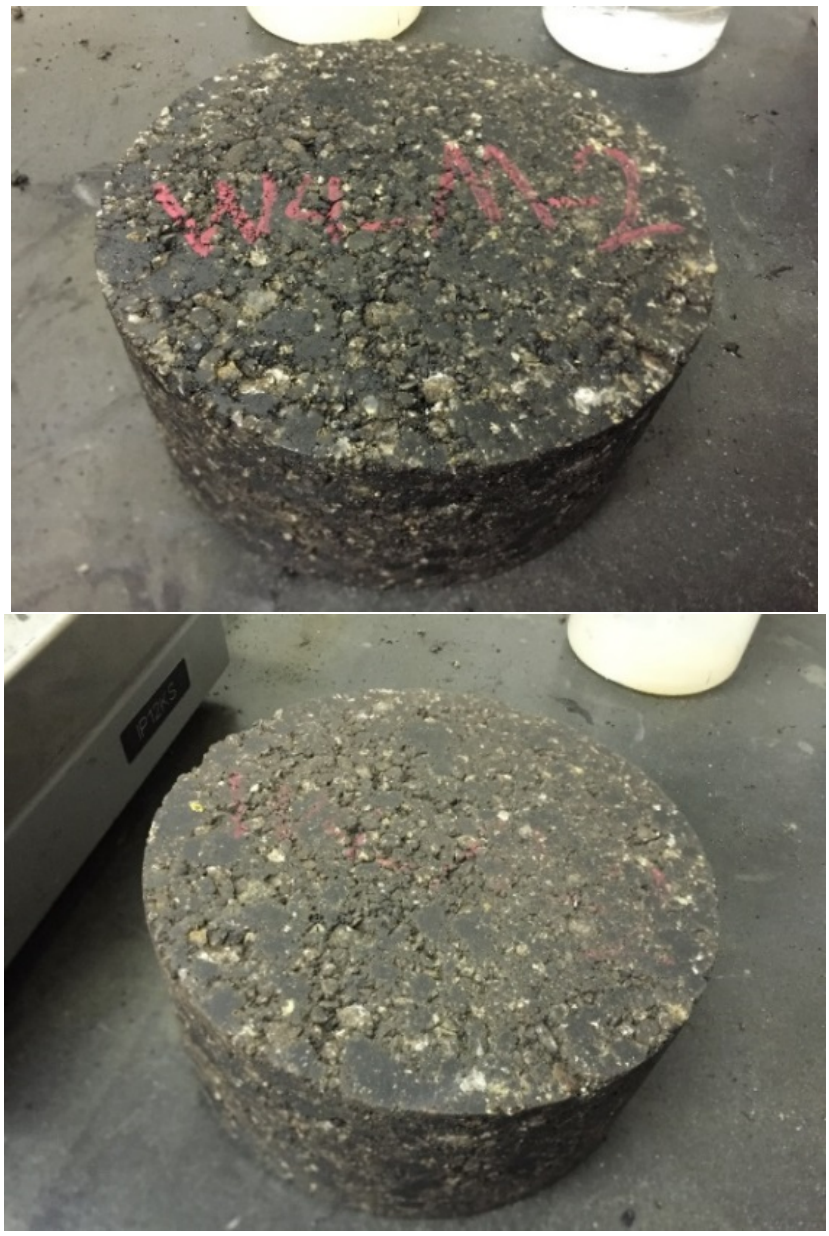

Figure 5 Specimens for the raveling test: before the test (top) and after the test (bottom)

Option B — Cold Mix for Binder Course or Low-Volume Secondary Roads

As discussed in the Task 3.1 report, by adding a lower-quality aggregate to replace the scalped No. 8 material, a cold mix suitable for a low-volume secondary road or binder course might be produced. This task consisted of initial laboratory work to determine the aggregate blend and optimize the emulsion and water content.

Blending of Aggregates

The reclaimed material used for this part of the test was acquired from the same stockpile as the material used in option A; however, a new sieve analysis was performed to determine the desired gradation, because of blending the millings with the coarse aggregate. To replace the scalped #8 aggregates from the millings, it was decided to blend the millings with virgin type C aggregates. A sieve analysis was performed on these virgin materials. Table 10 summarizes the results of sieve analysis on both the reclaimed millings and the virgin aggregates. Figure 6 and Figure 7 present the gradation charts for the reclaimed millings and the virgin A67 aggregates.

Table 10 Results of Sieve Analysis on the Reclaimed Millings and the Virgin Aggregates

Sieves		Materials (% Passing)	
US units	SI, mm units	A67	Reclaimed
1	25	100.000	100.000
3/4	19	92.721	100.000
1/2	12.5	53.181	100.000
3/8	9.5	25.423	98.270
#4	4.75	3.141	96.354
#8	2.36	1.390	72.101
#16	1.18	1.258	37.188
#30	0.6	1.234	18.764
#50	0.3	1.214	8.883
#100	0.15	1.174	3.393
#200	0.075	0.994	1.624
Pan	0	0.000	0.818

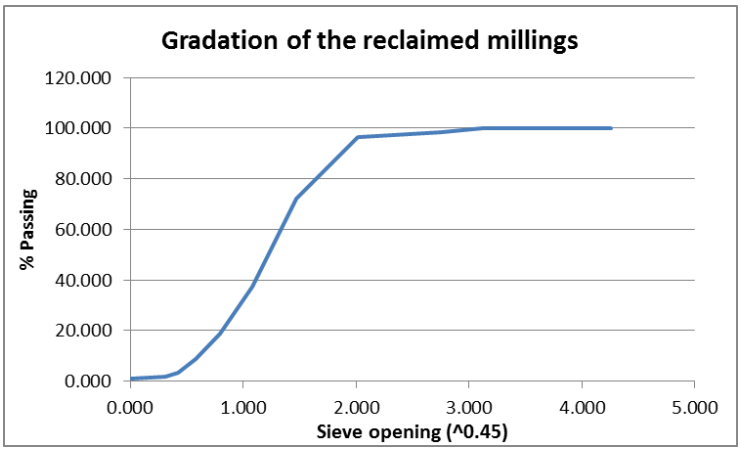

Figure 6 Gradation of the reclaimed millings

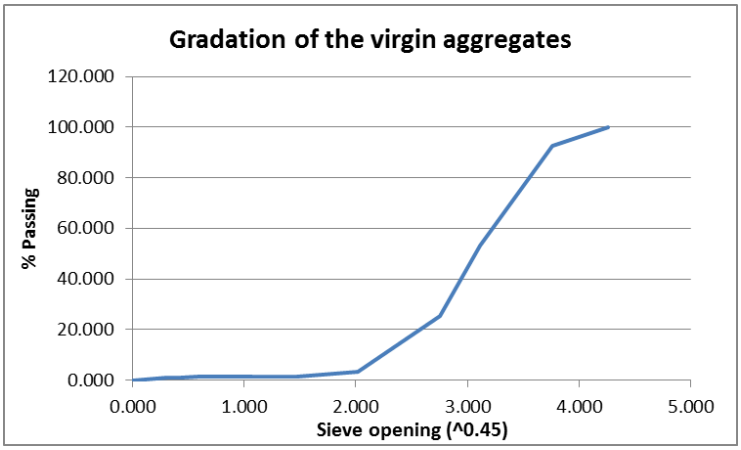

Figure 7 Gradation of the virgin aggregates

These materials were blended to achieve an aggregate meeting AASHTO M 323 requirements. Table 11 shows the AASHTO M 323 designation.

Table 11 AASHTO M 323 Designation for SuperPave Design (NMAS 19 mm)

Standard Sieve (mm)	Percent Passing Criteria
25.0	100
19.0	90-100
12.0	
9.50	
2.36	23-49
0.075	2.0-8.0

Table 12 demonstrates the proportion of each aggregate to produce the blend, and Figure 8 shows the gradation of the blend, along with the control zone.

Table 12 Aggregate Proportion in the Blend

Material	Proportion in the Blend
Reclaimed millings	0.55
A67 virgin aggregates	0.45

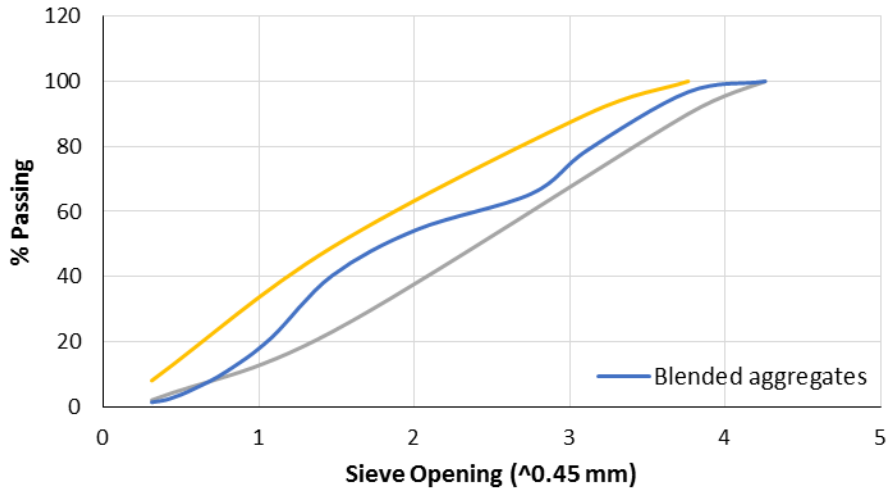

Figure 8 Gradation of the blended aggregates

Mix Design and Proportioning

To develop a cold mix suitable for binder course or low-volume secondary roads, a series of tests using the blended aggregates and one emulsion CSS-1H (Appendix A) were conducted. The cold mix was developed to optimize strength and density. A series of specimens was prepared and compacted at a range of emulsion and water contents. Tests were conducted using specimens with 62.5-mm (2.5 in) height. Table 13 summarizes the mix proportions of the test specimens. For each, density was determined and indirect tensile strength testing was conducted.

Table 13 Summary of Mix Proportions for Option B

Height (mm)	Water (%)	Emulsion (%)
62.5	2	3.0
		3.5
		4.0
	3	3.0
		3.5
		4.0
	4	3.0
		3.5
		4.0

Sample Preparation and Curing

The protocol provided for Work Order 3 at Penn State has also been followed for this testing (Appendix C). Due to the very high moisture content of the newly delivered materials, the reclaimed and virgin aggregates were air-dried for 72 hours. A moisture content test was performed on the air-dried reclaimed aggregates and the moisture content was determined as 0.05%, which demonstrates the efficiency of air-drying in removing the moisture from the material. The CSS-1H emulsion asphalt was heated in the 60 ℃ oven for 60 minutes prior to mixing. The reclaimed aggregates and the virgin A67 aggregates were batched and weighed carefully, and were blended for 60 seconds before adding water. The blended aggregates were then mixed manually with the required amount of water for 90 seconds prior to adding the emulsion. After adding the emulsion, the mixing was continued for at least 90 seconds to ensure the complete blending of reclaimed aggregates, water and emulsion. The mix was then moved to the environmental chamber, and was allowed to set for 30 minutes at 42 ℃ before compaction.

Determination of Bulk Specific Gravity of Specimens

After the 72-hour curing period in the 42 ℃ environmental chamber, the specimens were moved to room condition (25 ℃) for 2 hours to reach the ambient temperature. Bulk specific gravities (G_{mb}) of the specimens were then measured using the CoreLok® device before running the strength tests.

Determination of Indirect Tensile Strength of Specimens

The tensile strengths of the specimens were then measured according ASTM D6931 – 12. Table 14 summarizes the test results for the 62.5-mm specimens. It should be noted that the B-2-3.5-2 specimen was very weak and was not fit for IDT testing.

Table 14 Summary of Test Results for Specimens with 62.5-mm Thickness

Water (%)	Emulsion (%)	ID	IDT Strength (kPa)	Bulk Specific Gravity (G_{mb})	Gmm_e	Air Voids (%)
2	3	B-2-3-1	460.85	2.099	2.384	12.0
		B-2-3-2	449.42	2.113	2.384	11.4
	3.5	B-2-3.5-1	0.00	2.136	2.368	9.8
		B-2-3.5-2	0.00	0.000	2.368	n/a
	4	B-2-4-1	451.28	2.112	2.353	10.3
		B-2-4-2	501.00	2.145	2.353	8.8
3	3	B-3-3-1	480.42	2.140	2.384	10.2
		B-3-3-2	405.86	2.151	2.384	9.8
	3.5	B-3-3.5-1	420.79	2.121	2.368	10.4
		B-3-3.5-2	405.86	2.136	2.368	9.8
	4	B-3-4-2	554.76	2.037	2.353	13.4
		B-3-4-2	500.26	2.031	2.353	13.7
4	3	B-4-3-1	410.05	2.005	2.384	15.9
		B-4-3-2	466.10	1.994	2.384	16.4
	3.5	B-4-3.5-1	373.04	1.998	2.368	15.6
		B-4-3.5-2	462.65	2.002	2.368	15.5
	4	B-4-4-1	404.36	2.005	2.353	14.8
		B-4-4-2	424.65	1.982	2.353	15.8

Based on Table 14, the maximum tensile strength occurred for the B-3-4 specimens, with 3% moisture content and 4% emulsion content. These moisture and emulsion contents are both higher than the values found to be desirable for Option A (2% moisture and 3% emulsion content), which is rational considering the addition of the virgin material. The addition of the coarse aggregate increased the strength of the cold mix. Appendix D shows the results of the IDT on all specimens for option B.

Summary and Recommendations

The Task 5.2 test results for both Option A and Option B indicate potential for application, and are recommended for field evaluation. The preferable option would depend upon the availability of materials and project needs.

Option A uses only the fine reclaimed millings, requiring no use of virgin aggregates, and might be a suitable cold mix for a thin overlay project. The indirect tensile strength results for Option A are summarized in Figure 9 and Figure 10. Based on the reclaimed millings tested in this task, the desirable water content was recommended as 2%, while the desirable CSS-1H emulsion content was selected as 3%. The test specimens at this content produced indirect tensile strengths significantly above 300 kPa, which is a minimum relative acceptable benchmark.

In addition to a field trial, for future development of mix design requirements for Option A, it is recommended that additional laboratory testing be performed to assess if an upper limit on indirect tensile strength should be included to improve long-term field performance. The research needed to assess and set such a limit would include both indirect tensile and fracture energy testing.

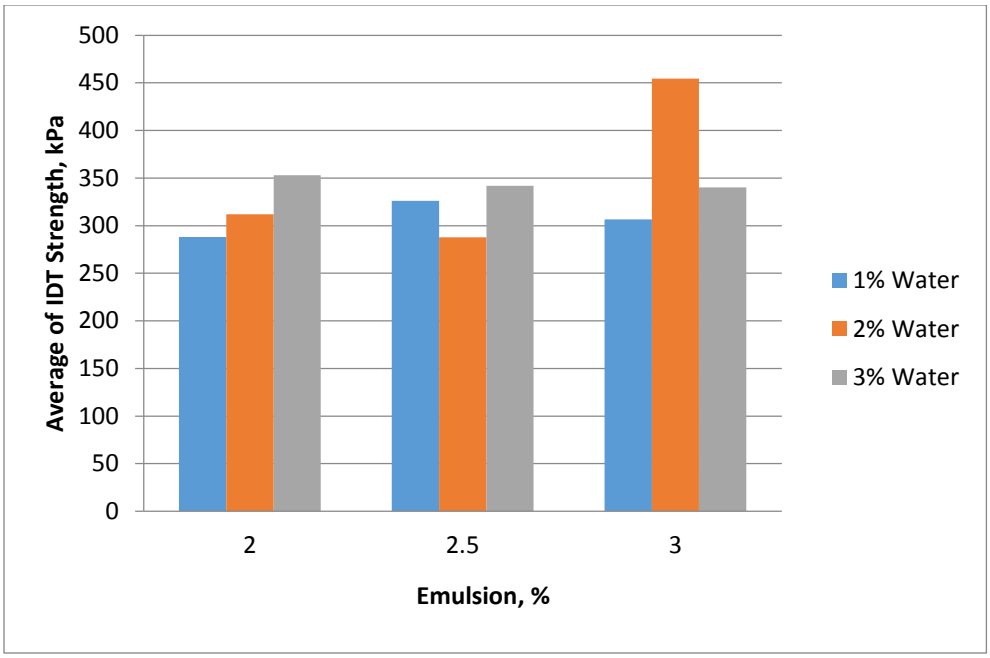

Figure 9 IDT Strength for the Option A laboratory specimens with 19-mm thickness

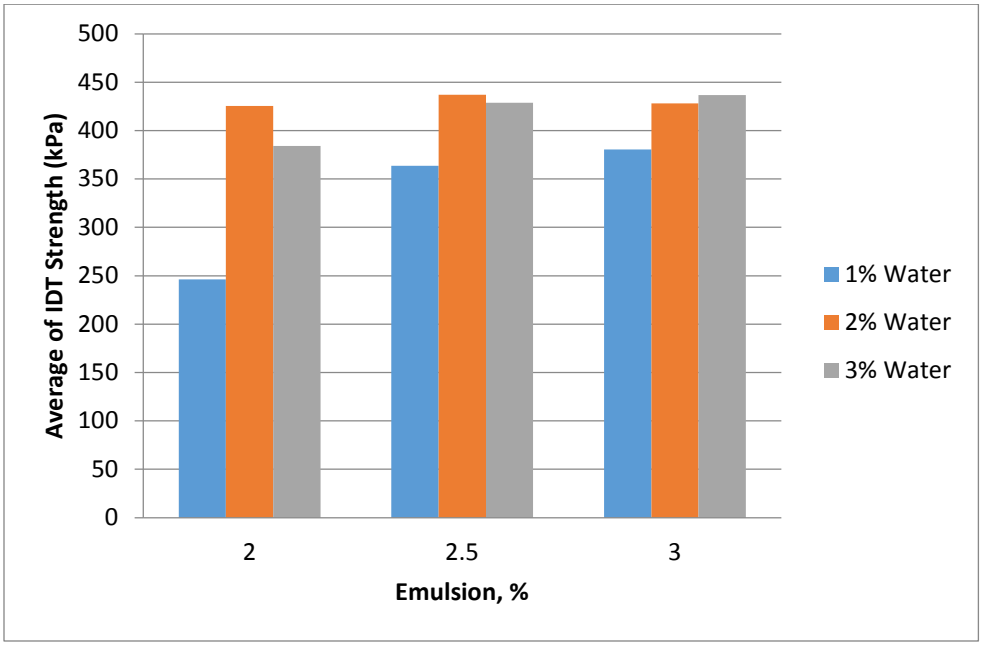

Figure 10 IDT Strength for the Option A laboratory specimens with 37.5-mm thickness

Option B incorporates virgin type C coarse aggregates into the cold mix with the reclaimed millings, and might be suitable as a binder course on a lower volume roadway. The indirect tensile strength results for Option B are summarized in Figure 11. Based on the reclaimed

millings tested in this task, and upon the addition of 45% virgin A67 type C aggregates, the maximum tensile strength occurred with 3% moisture content and 4% CSS-1H emulsion content.

These results are acceptable for an Option B field evaluation, although consideration could be given to first also testing with 4.5% emulsion, based upon examination of Table 14 and Figure 11. In addition, because of the addition of lower-quality virgin aggregates to Option B, it would be prudent to consider moisture damage resistance. Laboratory assessment of tensile strength ratio (TSR) and moisture damage is recommended.

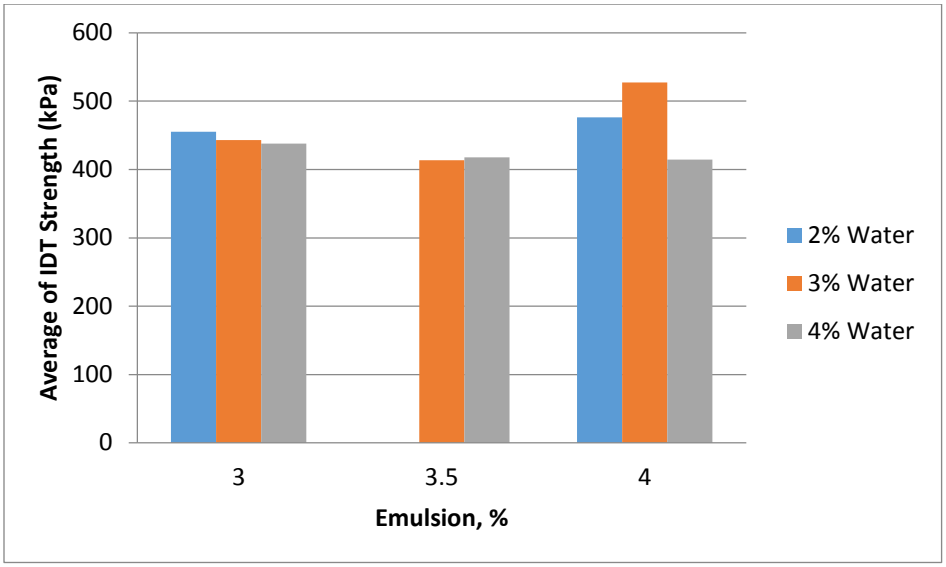

Figure 11 IDT Strength for the Option B laboratory specimens with 62.5-mm thickness

Appendix A

Midland Specifications for CSS1-H Emulsified Asphalt

MATERIAL SAFETY DATA SHEET

CSS-1H, TACK COAT

1. PRODUCT AND COMPANY INFORMATION

Product Name: CSS-1H, Tack Coat – Cationic Asphalt Emulsions
Synonym: Slow Setting Cationic Emulsion, 702-90, 702-9003
Company Name: **Midland Asphalt Materials Inc.**
Address: 640 Young Street
Tonawanda, New York 14151-0388

Phone No. 716-692-0730
Fax No. 716-692-0613

FOR CHEMICAL EMERGENCY, SPILLS, LEAKS,
FIRE, EXPOSURE OR ACCIDENT CALL CHEMTREC
800-424-9300

2. COMPOSITION / INFORMATION ON INGREDIENTS

Chemical Name	Percent	CAS Number	Exposure Limit
Asphalt	31-61 %	8052-42-4	5.0 mg/cu m ACGIH TLV(fumes)
Water	39-69 %	7732-18-5	N/A
Emulsifiers/Additives	Proprietary	Proprietary	N/A

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW:

- Brown to black fluid with hydrocarbon odor
- Exposure through inhalation and skin contact requires immediate medical attention.
- This material is a dispersion in which the continuous phase is water. As such, the material exhibits no flammability characteristics.
- Cured residue may produce combustible vapor in closed containers, emitting carbon dioxide, carbon monoxide, sulfur oxides and various hydrocarbons.

Health: Inhalation – Inhalation exposure is possible during spraying or stirring processes and may cause nausea, vomiting, diarrhea, and irritation of the nose, throat and lungs.

Skin Contact – May cause skin irritation causing redness and burning of the skin. Contact with the fumes may cause inflammation of sensitive skin membranes. Contact with heated material may cause thermal burns.

Eye Contact – May cause eye irritation causing conjunctivitis, stinging, tearing and redness. Contact with heated material may cause thermal burns.

Ingestion – Ingestion of this material is not likely during normal handling operations. Ingestion of large amounts of this material may be fatal.

4. FIRST – AID MEASURES

Inhalation – Immediately move individual away from the exposure area and into fresh air. Seek medical attention immediately. If victim is not breathing, begin artificial respiration. If victim's breathing is difficult, administer oxygen.

Skin Contact – This material is normally stored or handled at elevated temperatures that could cause scalding. if thermal burns occur, seek medical attention immediately. Any contact with material at ambient temperature should be rinsed from the skin with copious amounts of soap and water.

Eye Contact – Immediately move individual away from the exposure area and into fresh air. Flush eyes with copious amounts of water for at least 15 minutes while holding eyelids apart. Seek medical attention immediately. Contact lenses should not be worn while working with this chemical.

Ingestion – Do not induce vomiting – aspiration (inhaling fluid) may result. Ingestion of this material is not likely during normal handling operations. If victim becomes drowsy or unconscious, seek medical attention immediately. If spontaneous vomiting occurs, monitor for breathing difficulty.

5. FIRE FIGHTING MEASURES

NFPA Classification Health – 2 Fire – 0 Reactivity – 0 Other – N/A

Extinguishing media – Extinguishing foam, Dry Chemical

Fire Fighting Instructions – Avoid the use of water when fighting a fire involving this product. Wear an approved self-contained breathing apparatus with a full facepiece operated with positive pressure and chemical resistant personal protective equipment.

Specific Hazards – May form carbon dioxide, carbon monoxide and sulfur dioxide.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions – Wear the appropriate personal protective equipment including gloves, boots and tyvek suits.

Environmental precautions – Prevent runoff from entering sewers, streams and other bodies of water. Spilt materials should be placed in compatible containers. Residual product may be absorbed with sand, clay, earth, floor absorbent or other absorbent material and place in appropriate containers. Dispose of material in accordance with all local, state and federal regulations.

7. HANDLING AND STORAGE

Handling – Do not cut, grind, drill, weld, or reuse containers unless adequate precautions are taken against the hazards. Do not use excessive temperatures. Do not eat, drink or smoke in areas of use or storage. Empty containers may contain flammable, combustible or explosive vapor residue.

Storage – Store in tightly closed containers in a dry, isolated, well ventilated area away from sources of ignition and incompatibilities. Avoid extreme temperatures in storage. Emulsions will boil at temperatures greater than 212 degrees F and freeze at temperatures less than 32 degrees F.

8. EXPOSURE CONTROL / PERSONAL PROTECTION

Engineering measures – Provide sufficient general and/or local exhaust ventilation to maintain exposure below the TLV(s).

Respirators – A NIOSH/MSHA approved air purifying respirator with an appropriate cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits. Use positive pressure air supplied respirator if there is any potential for an uncontrolled release, exposure levels are not known, or any other circumstances where air-purifying respirators may not provide adequate protection. Avoid working with this material in closed areas with improper ventilation.

Eye/Face Protection – Safety glasses/goggles. A face shield is recommended for transfer operations or when splashing can occur. Eye washing facilities are to be readily available where splashing can occur. Do not wear contact lenses when handling this material.

Skin Protection – Use appropriate chemical resistant gloves when handling at room temperature. Long sleeved cotton shirt and full length cotton pants.

General Hygiene Considerations – Use good personal hygiene when handling asphalt products. Never wipe eyes or skin with PPE that has been exposed.

Other Protective Equipment – None recommended.

Occupational Exposure Limits – Hazardous Ingredients

	OSHA PEL	ACGIH TLV
Asphalt	N/A	5.0 mg/cu. m. (fumes)

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance .....Brown to black fluid
Odor .....Hydrocarbon odor
Boiling Point .....212 deg F (water)
Melting Point .....U/K
Evaporation Rate (Ether=1) .....N/A
Vapor Pressure (mm Hg) .....60 mmHg @ 100 deg F
Vapor Density (air=1) .....N/A
Solubility (Water).....Readily dispersed
Specific gravity (water=1).....1.00-1.01
% Volatile (By volume @ 68 deg F) ....43 % (including water)
VOC 5 g/l

10. STABILITY AND REACTIVITY

Stability – Stable under normal conditions.

Conditions to Avoid – Contact with string oxidizers, extreme temperatures in storage and handling.

Materials to Avoid – Strong oxidizing agents.

Hazardous Decomposition Products – Carbon dioxide, carbon monoxide, sulfur dioxide.

Hazardous Polymerization – Will not occur.

11. TOXICOLOGY INFORMATION

Type of Test	Route of Exposure	Species Observed	Dose Data
Asphalt TDLo	Intramuscular	Rodent (rat)	5400 mg/kg/24W-I
Asphalt TDLo	Skin	Rodent (mouse)	130 mg/kg/81W-I

12. ECOLOGICAL INFORMATION

Environmental Hazards – No significant data is available for this material.

13. DISPOSAL CONSIDERATIONS

This material is not specifically listed as a hazardous waste in federal regulations. However it could be considered hazardous as toxic, corrosive, ignitable, or reactive characteristic waste according to federal or state regulations. Dispose of in accordance with local, state, and federal regulations at an approved disposal facility.

14. TRANSPORT INFORMATION

DOT – This material is not regulated under DOT regulations unless it is shipped at temperatures greater than 100 deg C. It then becomes:

Elevated temperature liquid, n.o.s., class 9, UN3257, PG III

Placards – Class 9 and HOT

IATA – This material is not regulated under IATA regulations

IMDG – This material is not regulated under IMDG regulations.

UN NO – UN3257 (When shipped at temperatures > 100 deg C.)

15. REGULATORY INFORMATION

US Regulations:

ACGIH .....See Section 8
CAA Section 212 .....N/A
CERCLA .....N/A
IARC .....N/A
NTP .....N/A
OSHA .....See Section 8
SARA Title III .....N/A
TSCA .....All known components of this product are listed and comply

State Regulations:

MA Substance List .....Asphalt fumes
NJ RTK Hazardous Substance List .....Asphalt fumes
PA Hazardous Substance List .....Asphalt
Canadian WHMIS .....N/A

16. OTHER INFORMATION

REVISON NUMBER	REVISION DATE
Version 1	5/12/14

To the best of our knowledge, the information contained herein is accurate. However, neither Midland Asphalt Materials Inc. nor any of its subsidiaries assumes any liability whatsoever for the accuracy or completeness of the information contained herein. Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist. The possibility exists that the EU will not recognize this MSDS due to the fact that several components of the MSDS are reflective of ANSI Z 400.1-1998. Although ILO (International Labor Organization) has adopted ANSI Z.1-1998, ultimate disposition lies with the competent authority.

MIDLAND ASPHALT MATERIALS INC

Tests To Be Performed:

% Res-Evaporation	Penetration @ 25c	pH
% Res-Distillation	Elastic Recovery	
SF Vis @ 25 C	Float Test	
SF Vis @ 50 C	Demulsibility	
Sieve	Particle Charge	

LAB ID No.: —

Date Received: — Date Tested: 8/28/14

Technician(s): RPV Test No.: —

EMULSION TESTING WORKSHEET (1of2)

Sample Identification:

Project Name: QA/QC

Material Type: CSS-1h Source: 5-GAL BUCKET

Sample No.: — Sampled by: RPV

Sample Time: — Date: 9/2013

Sample Location: TONA Batch No.: —

Sample Temp.: — Level: —

Truck No.: —

Base Material: —

RESIDUE-EVAPORATION Tested by:

(ASTM D244 ASSHTO T59 CT330 CT331)

	Sample 1	Sample 2	Sample 3
W (tare-g)			
W (emul-g)			
W (total-g)			
RES. (%)			
AVE. (%)			

RESIDUE-DISTILLATION Tested by: RPV

(ASTM D224 ASSHTO T59)

W (still-g)	2252.0
W (still+emulsion-g)	—
W (emulsion-g)	200.00
W (still+residue+1.5): 2384.13 -1.5	2385.63
W (residue-g)	133.63
Residue %.:	66.80
Volume of water (ml)	64
Volume of oil (ml)	2 → 1.0%

TOT. DISTILLATE 66mL

VISCOSITY Tested by:

(ASTM D244 ASSHTO T59)

SF @ 25 C (secs)	
SF @ 50 C (secs)	
Zahn Cup @25C(secs)	

SIEVE Tested by: RPV

(ASTM D244 AASHTO T59)

W (sample-g)	516.42
W(sieve-g)	132.87
W (total-g)	132.94
Sieve %	.02

ELASTIC RECOVERY Tested by:

E1		ER1:	
E2		ER2:	
E3		ER3:	
		Avg	

FLOAT Tested by:

(ASTM D139 AASHTO T150)

PASS (>1200 seconds)	
FAIL (seconds0	

PENETRATION Tested by: RPV

(ASTM D5 AASHTO T49)

Trial 1:	69
Trial 2:	68
Trial 3:	67
Average:	68.0

DEMULSIBILITY Tested by:

(ASTM D244 AASHTO T59)

W (tare-g)	
W (emul-g)	
W (total-g)	
Demul. Res. % (A)	
Orig. Res. % (B)	
Demulsibility %	

PARTICLE CHARGE: Tested by:

(ASTM D244 AASHTO T59)

Current	Positive	Negative	Inconclusive	pH:

NOTES / COMMENTS:

#20

132.96

132.94

DIST. STARTED: 9:05 A.M

DIST. COMPLETED: 10:10 A.M.

FOR PENN STATE PROJECT

Appendix B

Procedure for Preparation and Testing of Cold Mix Asphalt with Reclaimed Aggregates

Emulsified Cold Mixes Using Reclaimed Asphalt

Procedure for Preparing Specimens and Conducting Mix Design

Scope

This procedure covers specimen preparation and required testing to establish mix design for cold mixes using reclaimed asphalt and emulsion.

Apparatus

Forced Draft Ovens: capable of maintaining temperature at 140 ºF to 300 ºF.
Balances
Sieves: ¾", 12.5mm, 9.5mm, #4, #8, #16, #30, #50, #100, #200 and PAN
Sample Splitter: Suitable for splitting RAP into representative and similar samples
Bucket Mixer
Superpave Gyratory Compactor
Pans
Corelok Device for bulk and maximum density measurements
Spatulas, trowels

Materials

Emulsions: CSS-1h and CSS-1hp
Reclaimed Asphalt (RAP): 500 pounds

Specimen Preparation

Moisture Content Determination:

A representative sample of RAP must be used to determine the moisture content through oven drying at 230 ºF (110 ºC) to a constant mass.

Drying Process:

RAP must be spread in pans or spread on worktable to dry overnight.

Sieve Analysis:

RAP must be crushed manually or through manipulation using gentle impact of a rod to remove clumped pieces. All materials larger than 3/4 inches must be scalped. Only material passing 3/4 inch must be used.

Conduct sieve analysis according to AASHTO T27 on three randomly selected samples of the RAP and determine gradation of each. Establish an average gradation based on these three gradations. Use this average gradation as the reference gradation.

Maximum Specific Gravity Determination (Gmm):

Prepare two samples of dried RAP and measure Gmm using CoreLok device. The loose RAP should be spread in a tray and cured at room temperature for 24 hours before measurement of Gmm.

Determine the amount of Material Needed for Compacted Specimens:

Use (1010 × Gmm) to determine the amount of material needed to deliver the height of specimen between 62 and 66 mm. For the raveling test, the height of the specimen is decided based on requirements of ASTM 7196-12.

Mixing/Curing Process:

Blending with Water: Mix the prepared batch of RAP and tap water according to the water content given in Tables 1 through 4. Mixing is conducted manually. Continue hand mixing for 90 seconds. Let the material sit for 2 minutes.

Blending with Emulsion: The wetted RAP will be mixed with emulsion at room temperature according to the emulsion content given in Tables 1 through 4. Blending emulsion with RAP takes place manually in a container suitable for such blending. The RAP is maintained at room temperature and the emulsion is maintained at 140 ºF (60 ºC) temperature before mixing. Mixing time will be 50 to 60 seconds.

Curing: Immediately after blending, the RAP-emulsion blend will be cured at 104 ºF (40C) oven for 30 minutes.

Table B-1 Specimen Preparation Matrix for Density/IDT – Number of Gyrations = 35

	Emulsion Content, %					**Total # of Specimens**
Water Content, %	**0**	**1.5**	**2.0**	**3.0**	**3.5**	
1	0	0	3	3	3	**9**
2	3	3	3	3	3	**15**
3	0	3	3	3	0	**9**
4	3	3	3	0	0	**9**

Table B-2 Specimen Preparation Matrix for Density/IDT – Number of Gyrations = 50

	Emulsion Content, %
Water Content, %	**Optimum from Table 1**
Optimum from Table 1	3

Table B-3 Specimen Preparation Matrix for Raveling Test

	Emulsion Content, %				
Water Content, %	**0**	**Optimum – 0.5%**	**Optimum**	**Optimum +0.5%**	**Total # of Specimens**
Optimum from Table 1	3	3	3	3	**12**

Table B-4 Specimen Preparation Matrix for Moisture Damage Test

	Emulsion Content, %
Water Content, %	**Optimum from Table 1**
Optimum from Table 1	8

Compaction/Curing Process:

Compaction: The cured material is placed in a perforated SGC mold and compacted to 50 gyrations. Compaction is conducted at room temperature and molds shall not be heated. Specimen must be extruded immediately after compaction. If desired height is not achieved, the amount of material needs to be adjusted and the process repeated. The number of specimens to be compacted is given in Tables 1 through 4. Immediately after compaction, weigh the specimen. Because of limitations on the mix curing time before compaction, mixing and compacting more than two specimens will require two persons. One person will conduct the mixing and a second person compacting samples and immediately weighing the samples after compaction.

Curing: Cure the compacted specimens at 104 ºF (40 ºC) for 72 hours. Let cool at room temperature for 2 to 3 hours before measuring Gmb. After measuring Gmb the specimens are placed into a 25 °C environmental chamber for 2 hours, after which one sample at a time is then removed and tested.

Density/Air Void Determination

Measure the density of compacted specimens using the CoreLok device. This measurement takes place after completion of the curing process according to the preceding section.

Back-calculate Gmm for each mix with emulsion using the Gmm of the RAP mix previously measured.

Determine air void of each specimen.

Measuring Indirect Tensile Strength (IDT)

Immediately after completion of the 72-hour 40 ºC curing, the compacted specimens shall be cured at 77 º F (25 ºC) for 2 to 3 hours before IDT testing. The IDT test must be conducted immediately afterward. Measure indirect tensile strength of the specimens prepared for IDT using a deformation rate of 50 mm/min.

Measuring Durability Using Raveling Test

Follow ASTM D7196-12 for making, compacting, and curing the samples.

Moisture Damage Evaluation

At the completion of the 72-hour 40 ºC curing, the compacted specimens shall be cooled at room temperature for 2 hours and the Gmb should be measured using CoreLok. Four of the specimens are randomly selected and processed for water conditioning based on the procedure described in PennDOT Bulletin 27 for moisture damage evaluation. After completion of conditioning, all 8 specimens are tested for IDT as explained under No. 6: Measuring IDT.

Appendix C

Results of Indirect Tensile Testing for Option A

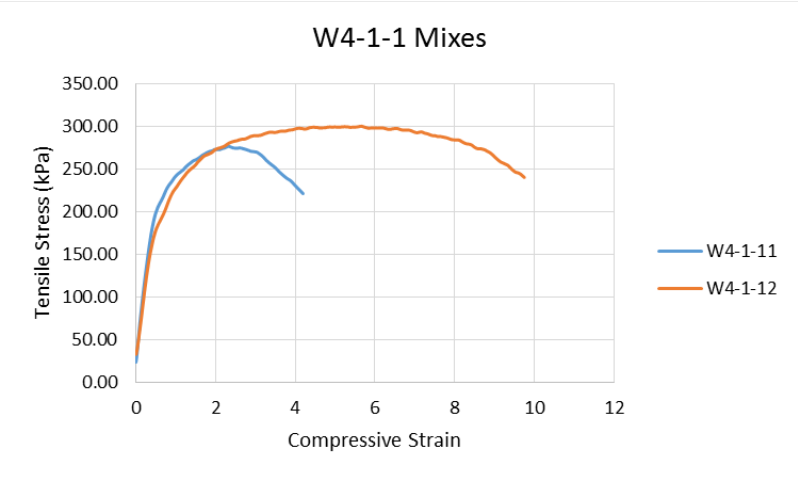

Figure C1 IDT test results on W4-1-1 Mixes

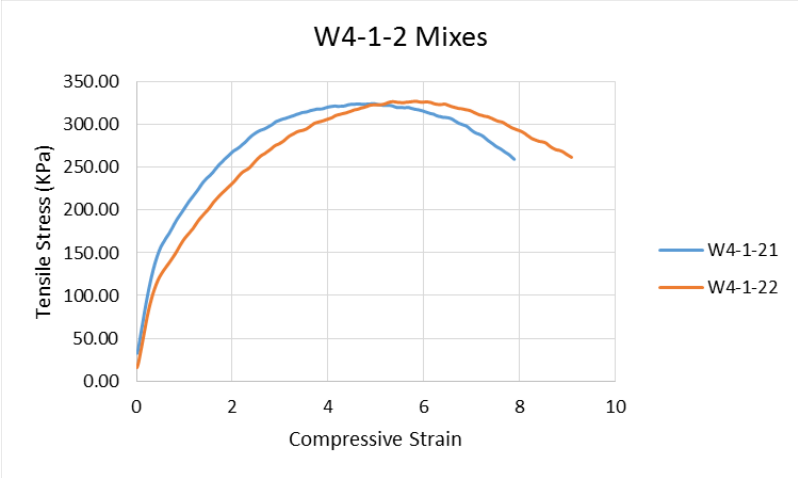

Figure C2 IDT test results on W4-1-2 Mixes

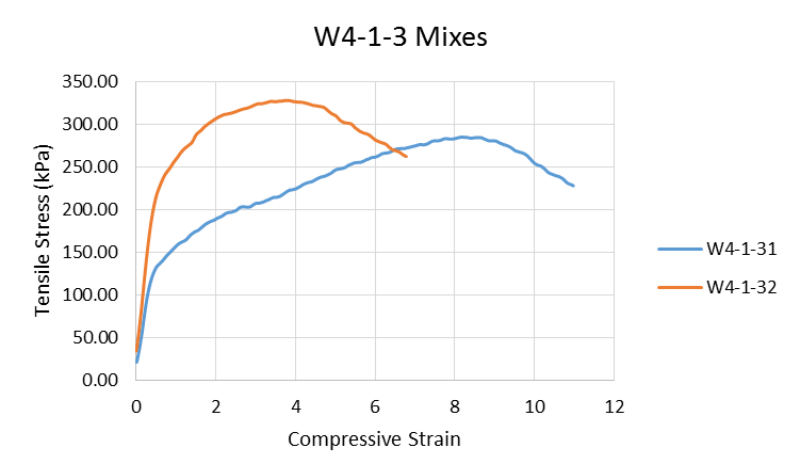

Figure C3 IDT test results on W4-1-3 Mixes

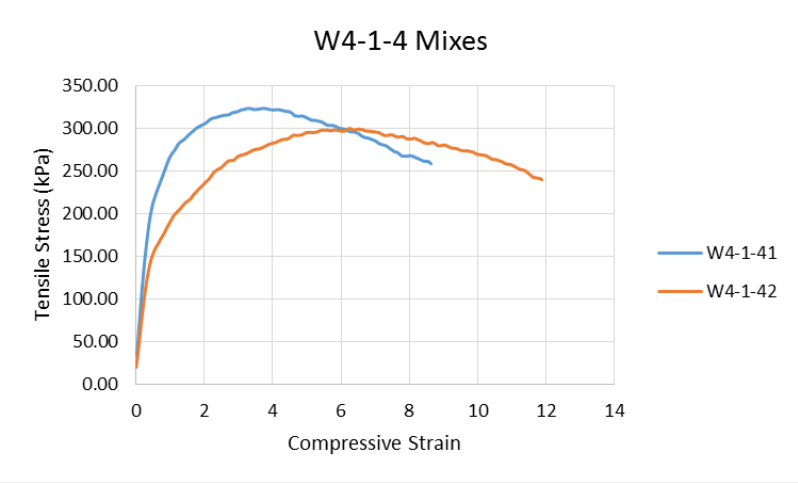

Figure C4 IDT test results on W4-1-4 Mixes

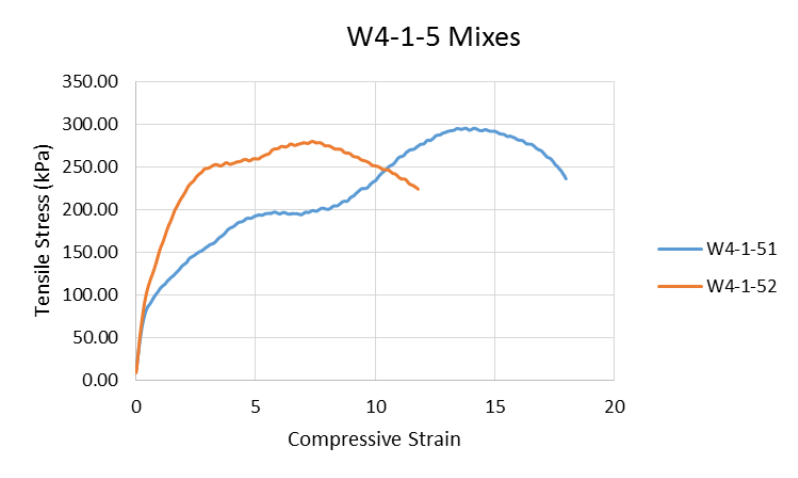

Figure C5 IDT test results on W4-1-5 Mixes

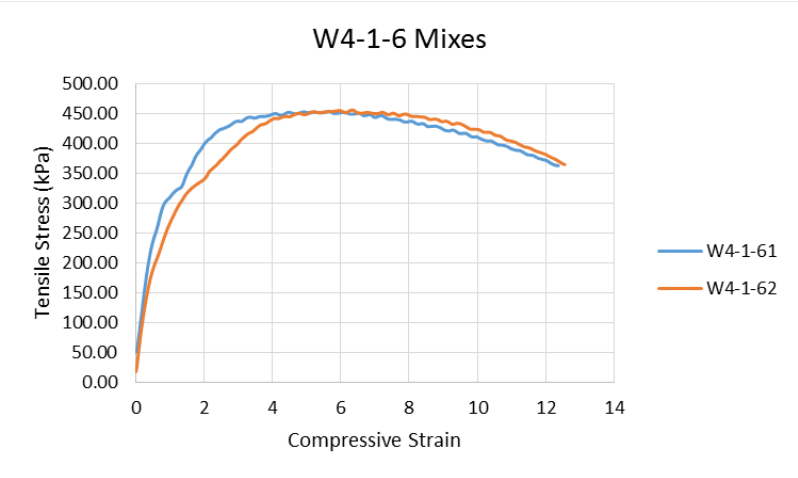

Figure C6 IDT test results on W4-1-6 Mixes

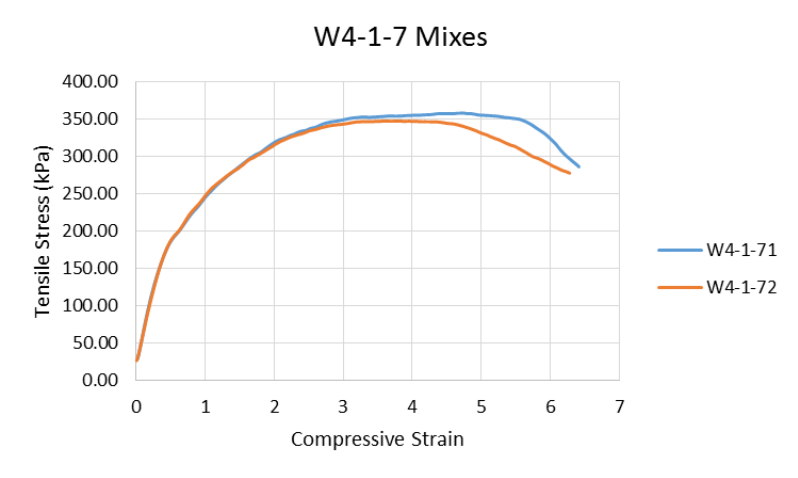

Figure C7 IDT test results on W4-1-7 Mixes

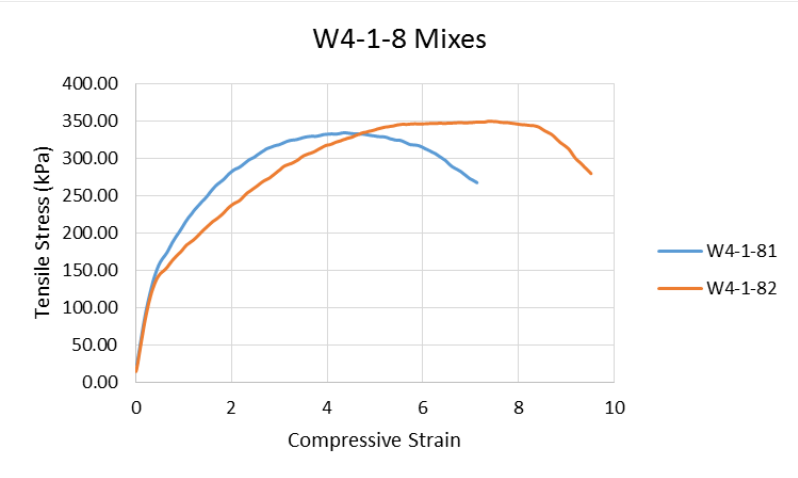

Figure C8 IDT test results on W4-1-8 Mixes

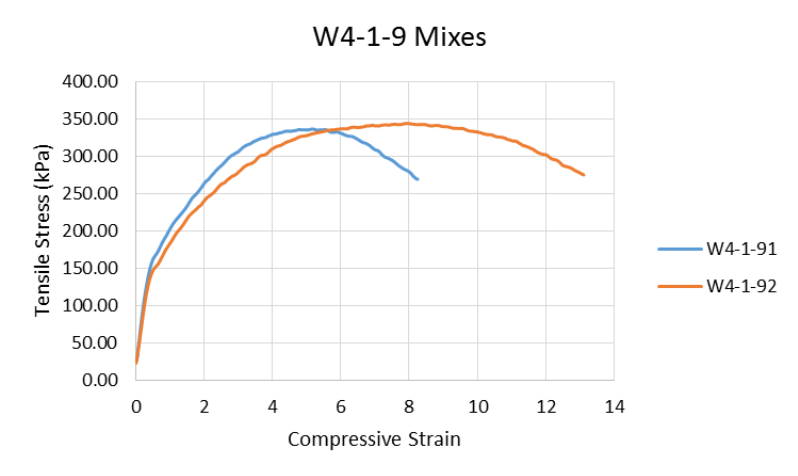

Figure C9 IDT test results on W4-1-9 Mixes

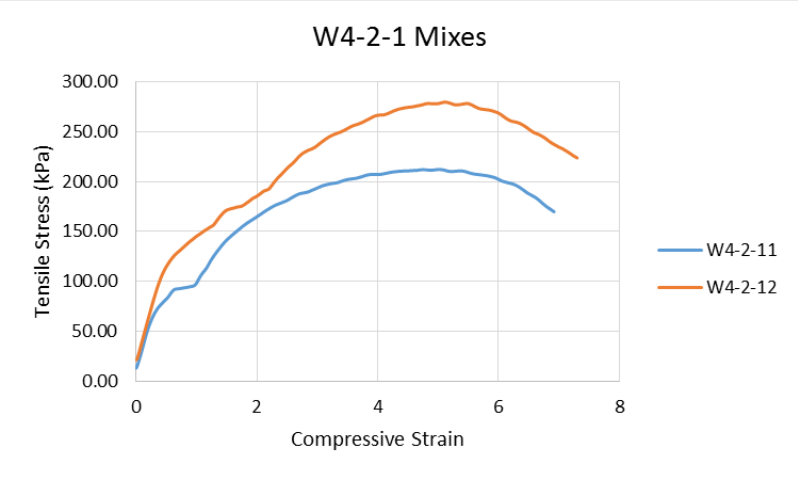

Figure C10 IDT test results on W4-2-1 Mixes

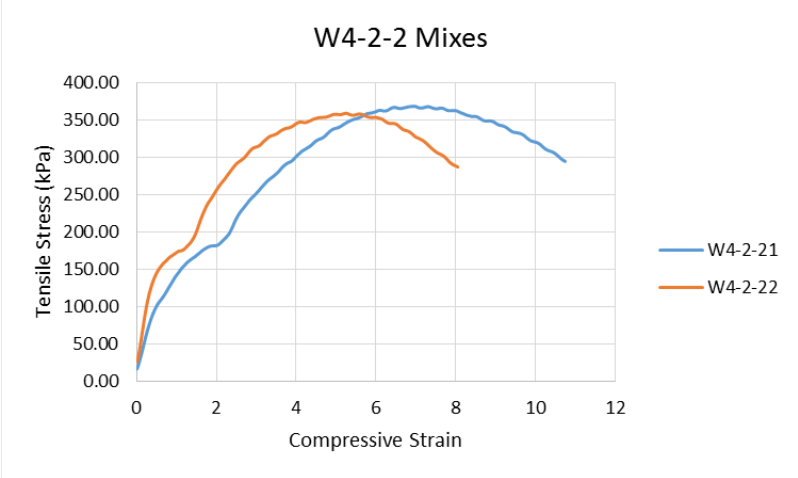

Figure C11 IDT test results on W4-2-2 Mixes

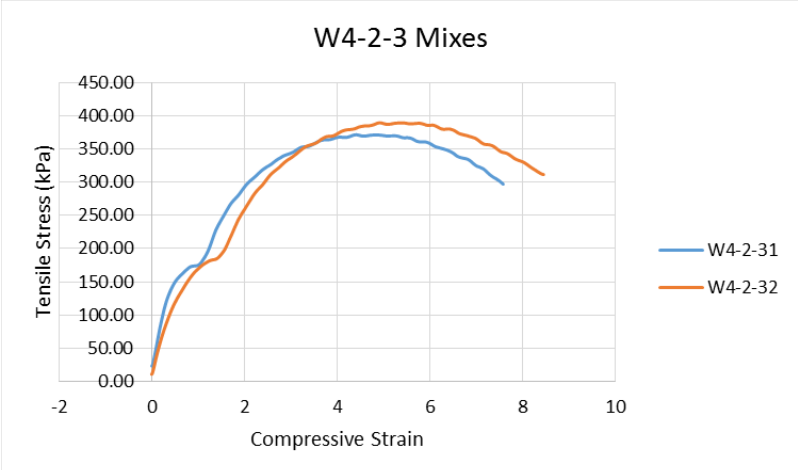

Figure C12 IDT test results on W4-2-3 Mixes

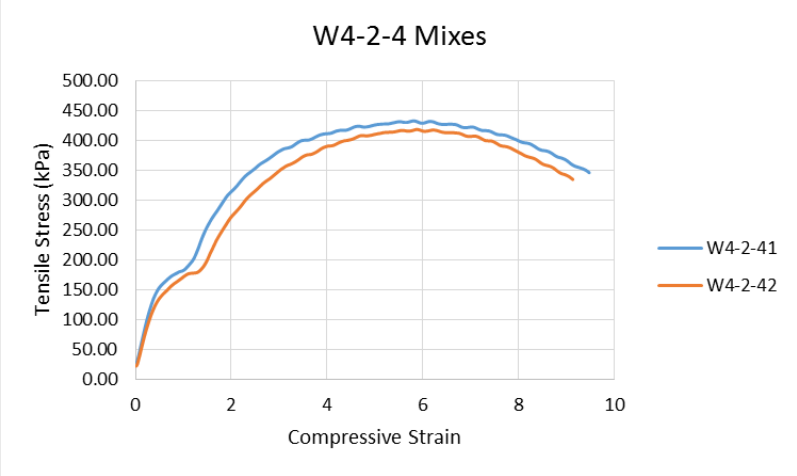

Figure C13 IDT test results on W4-2-4 Mixes

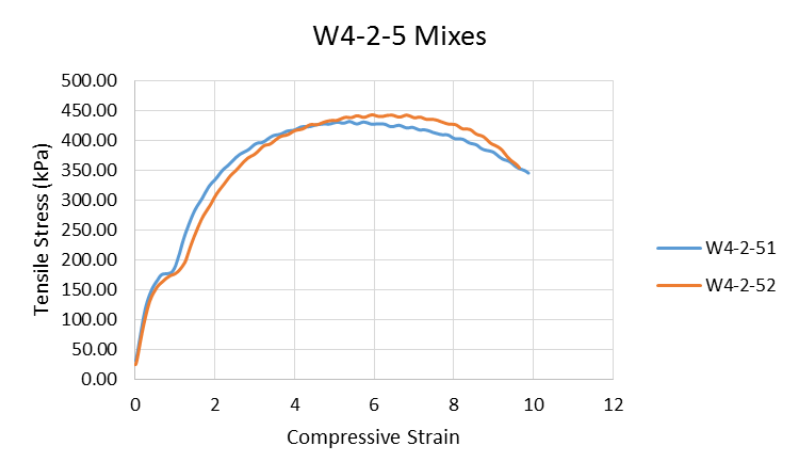

Figure C14 IDT test results on W4-2-5 Mixes

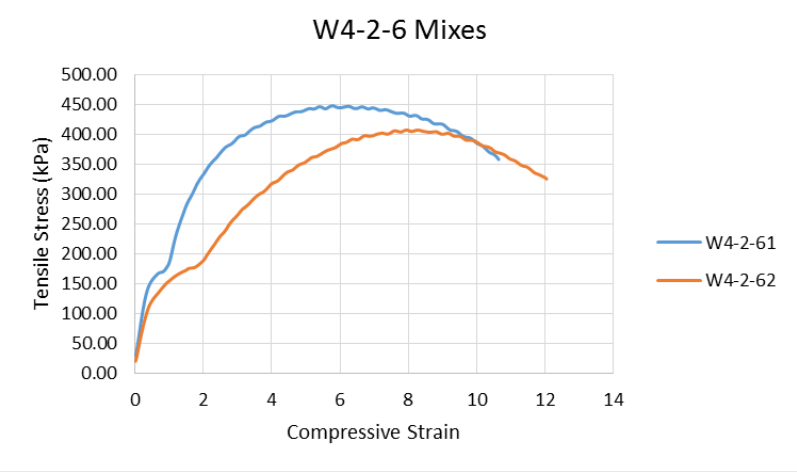

Figure C15 IDT test results on W4-2-6 Mixes

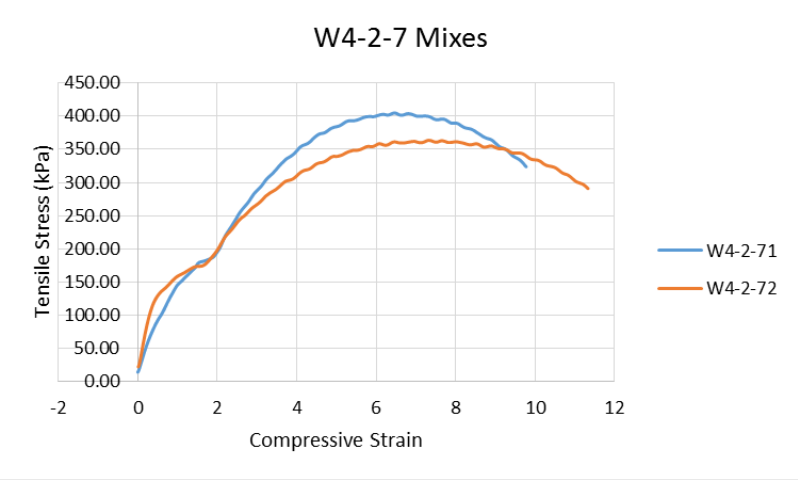

Figure C16 IDT test results on W4-2-7 Mixes

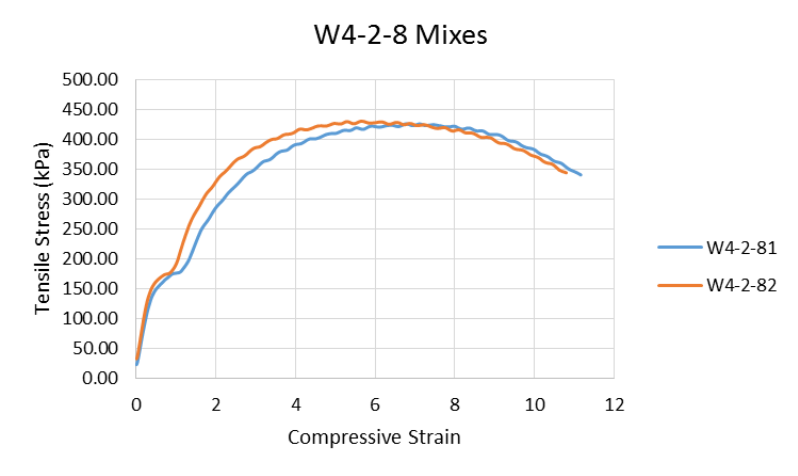

Figure C17 IDT test results on W4-2-8 Mixes

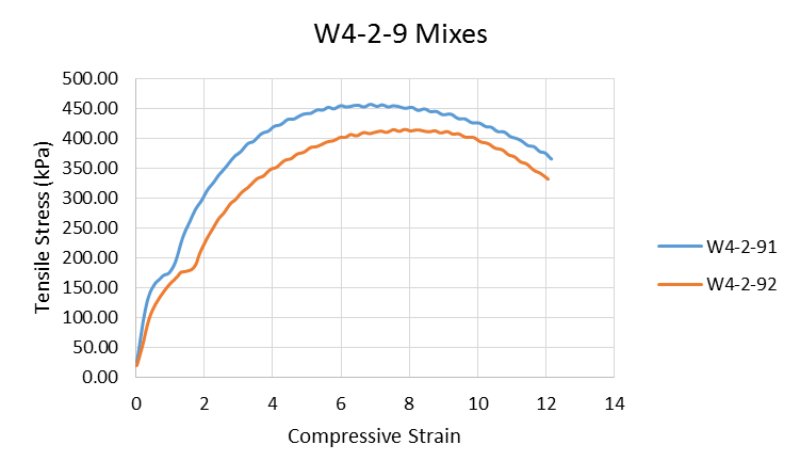

Figure C18 IDT test results on W4-2-9 Mixes

Appendix D

Results of Indirect Tensile Testing for Option B

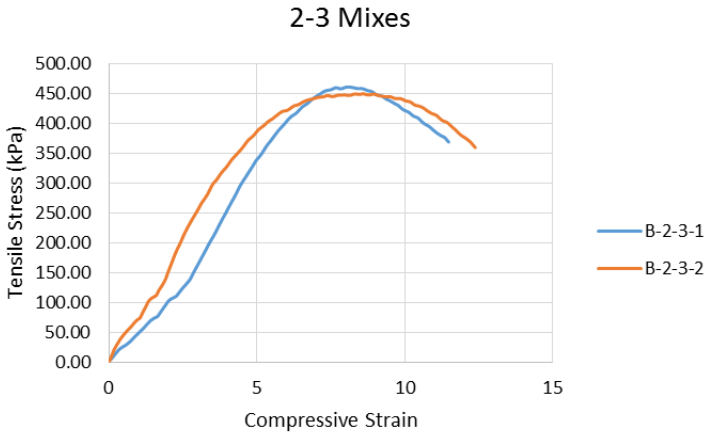

Figure D1 IDT test results on W4-B-2-3 Mixes

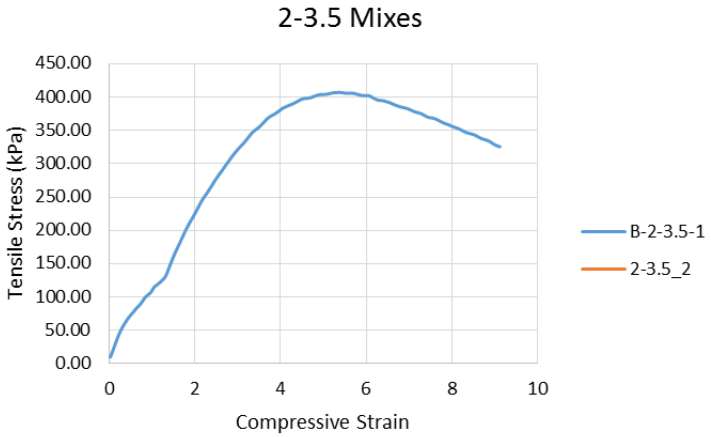

Figure D2 IDT test results on W4-B-2-3.5 Mixes

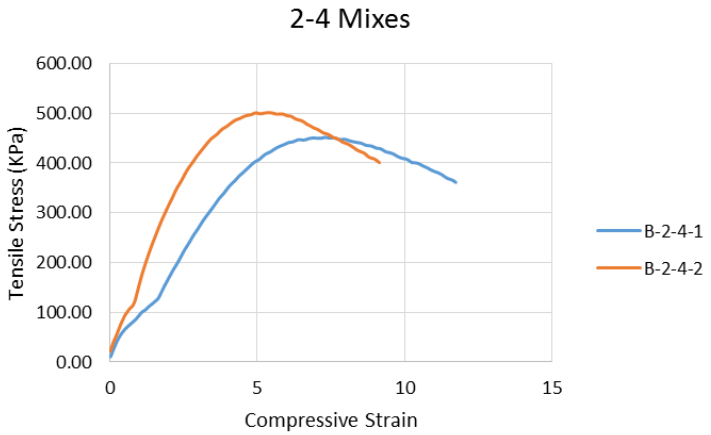

Figure D3 IDT test results on W4-B-2-4 Mixes

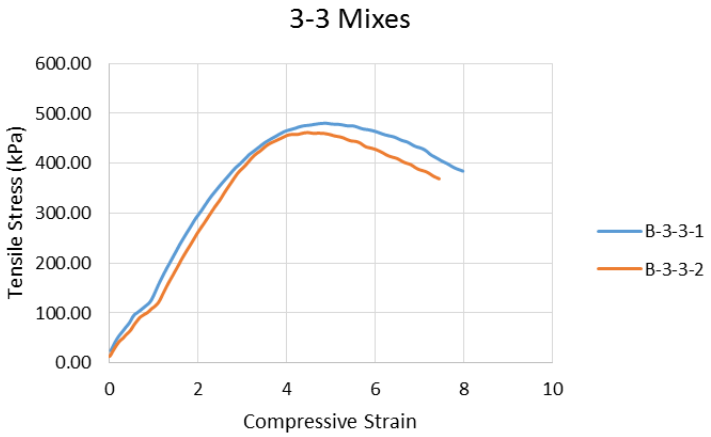

Figure D4 IDT test results on W4-B-3-3 Mixes

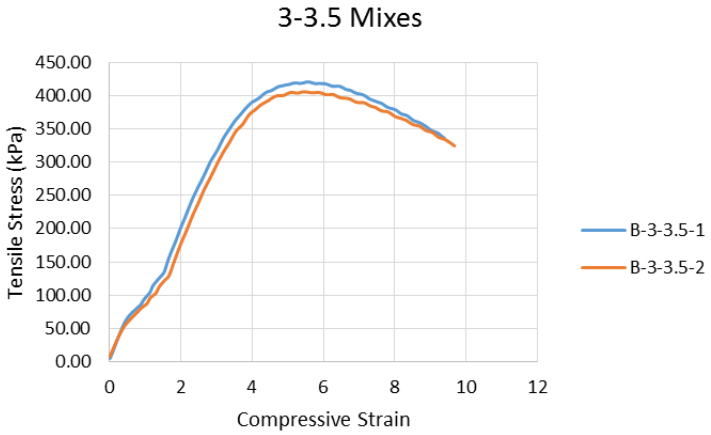

Figure D5 IDT test results on W4-B-3-3.5 Mixes

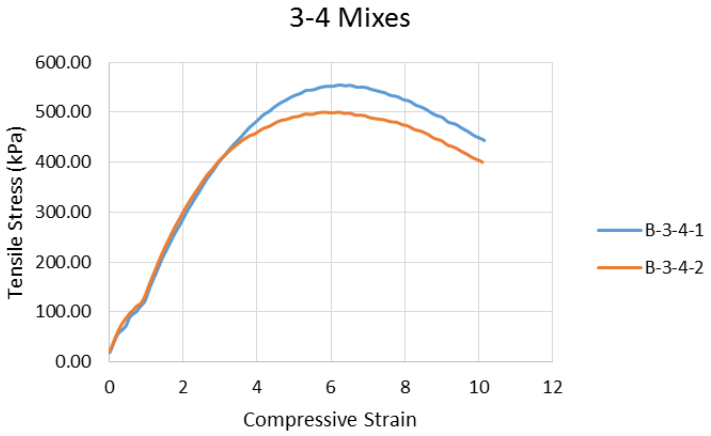

Figure D6 IDT test results on W4-B-3-4 Mixes

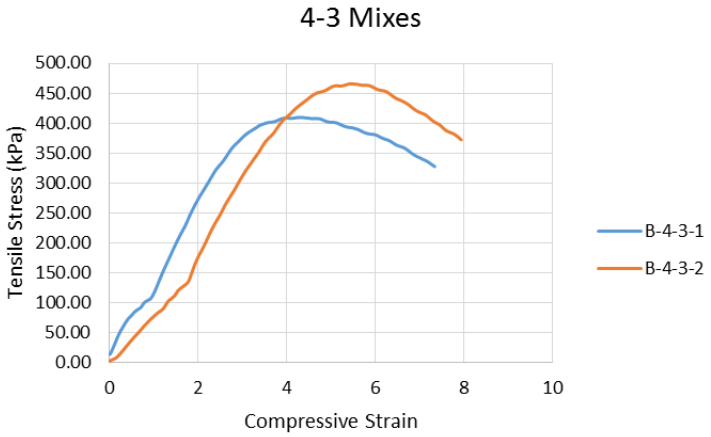

Figure D7 IDT test results on W4-B-4-3 Mixes

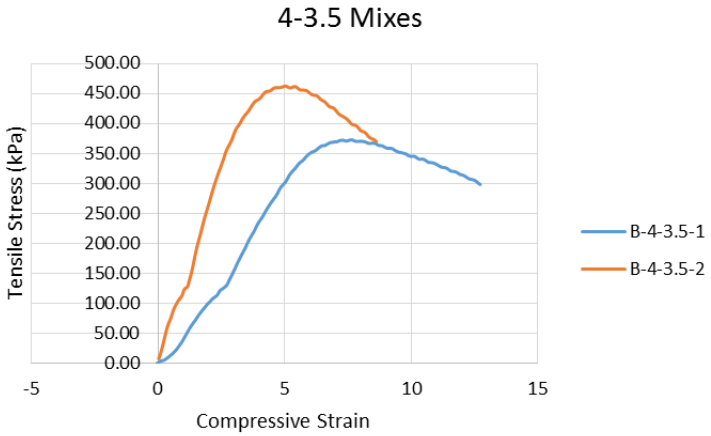

Figure D8 IDT test results on W4-B-4-3.5 Mixes

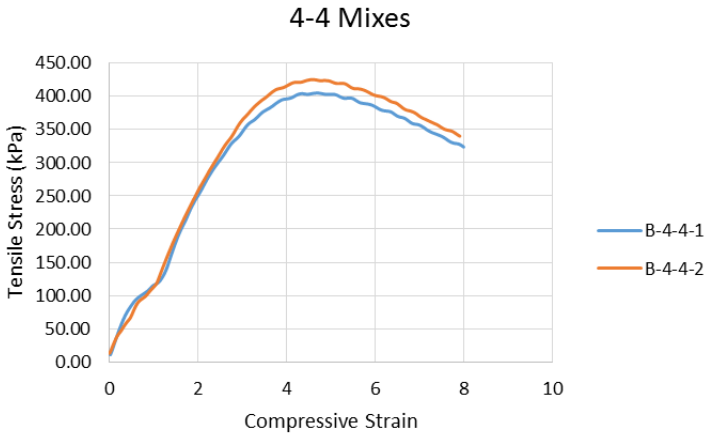

Figure D9 IDT test results on W4-B-4-4 Mixes